PHILOSOPHICAL TRANSACTIONS.

XV. *New Experiments upon Gun-powder, with occaſional Obſervations and practical Inferences; to which are added, an Account of a new Method of determining the Velocities of all Kinds of Military Projectiles, and the Deſcription of a very accurate Eprouvette for Gun-powder. By* Benjamin Thompſon, *Eſq, F. R. S.*

Read March 29, 1781.

THESE experiments were undertaken principally with a view to determine the moſt advantageous ſituation for the vent in fire-arms, and to meaſure the velocities of bullets, and the recoil under various circumſtances. I had hopes alſo of being able to find out the velocity of the inflammation of gun-powder, and to meaſure its force more accurately than had hitherto been done. They were begun in the month of July in the year

1778, at Stoneland Lodge, a country ſeat of Lord GEORGE GERMAIN's, and I was aſſiſted by the reverend Mr. BALE, rector of Withyham, who lives in the neighbourhood.

The weather proved remarkably favourable for our experiments, being ſettled and ſerene, ſo that the courſe of them was never interrupted for a whole day by rain or by any accident. The mercury in the barometer ſtood in general pretty high, and the temperature of the atmoſphere was very equal, and moderately warm for the ſeaſon. In order that each experiment might, as nearly as poſſible, be under ſimilar circumſtances, they were all made between the hours of ten in the morning and five in the afternoon: and after each diſcharge the piece was wiped out with tow till all the inſide of the bore was perfectly clean, and as bright as if it had juſt come out of the hands of the maker; and great care was taken to allow ſuch a ſpace of time to elapſe between the firings, as might render the heat of the piece nearly the ſame in every experiment.

A deſcription of the apparatus.

The barrel principally uſed in theſe experiments was made by WOGDON, one of the moſt famous gunſmiths in London; and nothing can exceed the accuracy with which it is bored, or the fineneſs of the poliſh on the inſide. It is made of the very beſt iron, and, agreeably to Mr. ROBINS's advice, I took care to have it well fortified in every part, that there might be no danger of its burſting. Its weight and dimenſions may be ſeen in the table of the weight and dimenſions of the apparatus, p. 242.

Fig. 1. Repreſents a longitudinal ſection of a part of the barrel, with the apparatus firſt made uſe of for ſhifting the vent from one part of the chamber to another, or rather for moving

the bottom of the chamber further from, or bringing it nearer to, the vent, in order that the fire might be communicated to the powder in different parts of the charge.

a, *b*, repreſent the lower part of the barrel.

c, is the breech-pin, which is perforated with a hole four-tenths of an inch in diameter, the axis of which coincides with the axis of the bore.

Into this hole the ſcrew *h*, *n*, about four inches in length, is fitted; to the end of which, *n*, that paſſes up into the bore, is fixed a piſton *o*, *p*, which, by means of collars of oiled leather, is made to fit the bore of the piece very exactly. The end of the piſton *p*, neareſt the muzzle, is of braſs, and forms a moveable bottom to the bore, which by turning the ſcrew *h*, *n*, by means of the handle *m*, is brought nearer to, or removed further from, the fixed vent *v*, by which means the powder is lighted at any aſſignable diſtance from the bottom of the charge.

But the length of the bore being altered by moving the piſton, which occaſioned a ſmall inaccuracy, and ſome inconvenience attending the apparatus, it was laid aſide, and another repreſented by fig. 2. was ſubſtituted in the room of it.

a, *b*, is a ſection of part of the barrel as before, and *c* is the breech-pin, which being perforated with a ſmall hole through its center receives the ſcrew *f*, *g*, which is about two-tenths of an inch in diameter, and four inches long. This ſcrew being perforated with a very ſmall hole, ſerves to convey the fire into the chamber of the piece, and by ſcrewing it further up into the bore, or drawing it backwards, the fire is communicated to different parts of the charge.

But this method being found to be not intirely free from inaccuracies and inconveniencies, a third was ſubſtituted in the room of it, which was found to anſwer much better than either of the preceding.

The end of the bore was now firmly cloſed by a ſolid breech-pin *p*, fig. 3. and three vent holes *m*, *n*, and *o*, were made in the barrel; one of them, *m*, even with the bottom of the bore, and the other two at different diſtances from it. Any two of theſe vent holes, as *n* and *o* for inſtance, being cloſed up by ſolid ſcrews, a perforated ſcrew, or vent tube *v*, was ſcrewed into the third, which ſerved to contain the priming, and to convey the fire to the powder lodged in the bore of the piece.

Sometimes a longer vent-tube, repreſented by fig. 4. was made uſe of; which, paſſing through the powder in the chamber of the piece, communicated the fire immediately to that part of the charge that lay in the axis of the bore.

Another vent-tube alſo was uſed occaſionally, which differs in many reſpects from both thoſe that have been deſcribed. It is ſo conſtructed as to convey the fire to the charge; but, as ſoon as the powder in the chamber of the piece begins to kindle, and the elaſtic fluid to be generated, the vent is firmly cloſed by a valve, and no part of the generated fluid is permitted to eſcape. This I ſhall call the *valve-vent*, and it is repreſented by fig. 5. upon an enlarged ſcale, that the parts of it may appear more diſtinct.

a, *b*, is a longitudinal ſection of a ſmall portion of the ſolid ſide of the barrel.

c, *d*, is the vent-tube, which is in all reſpects like the ſhort vent-tube commonly made uſe of, except only that in this the end of the vent-hole (*c*) which goes into the chamber is enlarged in the form of the wide end of a trumpet or funnel.

To this enlarged aperture the valve, *v*, is accurately fitted, and by means of the ſmall ſtem or tail, *t*, which is fixed to the valve, and which paſſes up through the vent-hole, and is connected with the ſpring S, the valve is preſſed, or rather drawn into its place, and the vent is cloſed. The ſtem of the valve was at firſt made cylindrical; but, in order to make way for the priming to paſs down to the valve, one-half of its ſubſtance was taken away, as is repreſented in the figure.

When this vent is primed, the ſpace between the vent hole and the ſtem of the valve is filled with fine-grained powder, and the valve is gently opened by preſſing upon the end of the ſtem till one or more grains of powder lodge themſelves between the valve and the aperture; which preventing the valve from cloſing again, a ſmall opening is left for the paſſage of the flame into the chamber of the piece: therefore, when the priming is lighted, the fire paſſing down the vent, and entering the chamber, inflames the charge, and the ſmall grains of powder that were lodged between the valve and the aperture being deſtroyed by the flame in its paſſage through the vent, the valve immediately cloſes, and prevents the eſcape of any part of the elaſtic fluid generated by the inflammation of the powder in the chamber of the piece. The preſſure of this fluid upon the valve aſſiſts the action of the ſpring, by which means the valve is more expeditiouſly and more effectually cloſed.

The valve was very accurately fitted to the aperture by grinding them together with powdered emery, and afterwards poliſhing them one upon the other. And it is very certain, that no part of the elaſtic fluid made its eſcape by this vent; for, upon firing the piece, there was only a ſimple flaſh from the exploſion of the priming, and no ſtream of fire was to be ſeen iſſuing from the vent, as is always to be obſerved when a common vent is made uſe of, and in all other caſes where this fluid finds a paſſage.

In order that every part of the apparatus employed in theſe experiments might be as perfect as poſſible, all the more delicate parts of it were executed by Mr. FRASER, mathematical inſtrument-maker in Duke's Court, St. Martin's Lane, and, among the reſt, all the contrivances juſt deſcribed relative to the vent.

The velocities of the bullets were determined by means of a pendulum, according to the method invented by Mr. ROBINS.

The pendulum I made uſe of (fig. 6.) is compoſed of a circular plate of hammered iron (*a*), 13 inches in diameter, and 0,65 of an inch thick, to which is firmly faſtened a bar of iron (*b*, *c*) 56,5 inches in length, 2,6 inches broad, and half an inch in thickneſs, by which it is ſuſpended by means of two pivots (*d*, *e*) at the end of the bar (*c*), and at right angles to its length. Theſe pivots being very accurately finiſhed, and moving on poliſhed grooves, which were kept conſtantly oiled to leſſen the friction, the vibration of the pendulum was very free, as appeared by the great length of time its vibrations continued after it had been put in motion, and was left to itſelf. To the circular plate of the pendulum, targets of circular pieces of wood of different thickneſſes were fixed, which in the courſe of the experiments were often ſpoiled and replaced: and, in order to mark the weight and dimenſions of the pendulum in each experiment, the pendulums are numbered according to the different targets that were made uſe of; and the weight and dimenſions of each pendulum are ſet down in a table at the end of the deſcription of the apparatus.

The target of the pendulum N° 1. was made of a circular piece of elm-plank, 3½ inches thick, and equal in diameter to the iron plate of the pendulum to which it was fixed; but this target being too thin was very ſoon ruined.

The pendulum N° 2. was furniſhed with two targets, which were circular pieces of very tough oak-plank, near five inches thick, placed on oppoſite ſides of the plate of the pendulum, and firmly fixed to it by ſcrews, and to each other by iron ſtraps. When one of theſe targets was ruined, the pendulum was turned about, and the other was made uſe of. This pendulum laſted from experiment N°9. to experiment N°39. when it was ſo much ſhattered as to be rendered unfit for further ſervice.

The pendulum N° 3. was like the pendulum N° 2.; only, inſtead of oak, elm-plank near ſeven inches in thickneſs was made uſe of for the targets. This pendulum ſerved from experiment N° 40. to experiment N° 101. incluſively.

But finding that targets made of planks of the tougheſt wood were very ſoon ſhattered to pieces by the bullets, I compoſed the pendulum N° 4. in a different manner. Inſtead of circular pieces of plank, ſolid cylinders of elm-timber were made uſe of for the targets, ſo that the bullets now entered the wood in the direction of its fibres. Theſe cylinders are 13 inches in diameter, and about 5½ inches in length, hooped with iron at both their ends to prevent their ſplitting, and firmly faſtened to the plate of the pendulum, and to each other by four iron ſtraps. This pendulum laſted till the experiments were finiſhed. It is ſtill in being, and appears to be very little the worſe for the ſervice it has undergone.

Fig. 7. ſhews the two ends of the pendulum upon a large ſcale, together with the hooks or grooves by which it was ſuſpended.

a, *b*, is the bar of the pendulum, which is ſeen broken off, as there is not room to ſhew the whole of its length.

c, *d*, are the pivots by which it was ſuſpended.

e, is the circular plate of the pendulum, to which

f, *g*, two circular targets, are faſtened by ſcrews, and by means of the iron ſtraps, 1, 2, 3, 4, which are nailed to the edges of the targets.

h, *k*, are the hooks which ſerved inſtead of grooves to receive the pivots, *c*, *d*, of the pendulum.

The hooks were firmly fixed to the horizontal beam R. S. which ſupported the whole apparatus by means of three ſcrews *m*, *n*, *o*, which paſſed through three holes in the plate that connects the two hooks. When the hooks were faſtened to the beam, the middle ſcrew, *n*, was firſt put into its place, and the pendulum was allowed to ſettle itſelf in a poſition truly perpendicular, after which the grooves were immoveably fixed by means of the ſcrews *m*, *o*.

The chord of the arc, through which the pendulum aſcended in each experiment, was meaſured by a ribbon, according to the method invented and deſcribed by Mr. ROBINS.

The recoil was meaſured in the following manner. The barrel was ſuſpended in an horizontal poſition (and nearly in a line with the center of the target) by two ſmall pendulous rods, 64 inches in length, and 25,6 inches aſunder; which being parallel to each other, and moving freely upon poliſhed pivots about the axes of their ſuſpenſion, and upon two pair of trunnions that were fixed to the barrel, formed, together with the barrel, a compound pendulum; and from the lengths of the vibrations of this pendulum, the velocity with which the barrel began to recoil, or rather its greateſt velocity, was determined.

But in order that the velocity of the recoil might not be too great, ſo as to endanger the apparatus when large charges were made uſe of, it was found neceſſary to load the barrel with an additional weight of more than 40 lbs. of iron.

This additional weight of iron, which I ſhall call the *gun carriage*, as it was ſo conſtructed as to ſerve as a carriage to the barrel, is compoſed of a bar of hammered iron 28 inches in length, 2,6 inches broad, and half an inch in thickneſs, which is bent in the middle of its length in ſuch a manner, that its two flat ſides or ends are parallel to each other, and diſtant aſunder two inches. In the middle of this bar where it is bent is a hole in the form of an oblong ſquare, which, receiving the end of the breech-pin, ſupports the lower end or breech of the barrel. The other end of the barrel is ſupported and confined in the following manner. A ring or hoop of iron, near half an inch thick, and two inches in diameter, is placed in a vertical poſition between the parallel ſides of the bar, and near its two ends, and firmly fixed to them by ſcrews. The barrel paſſing through the middle of this ring is ſupported upon the ends of three ſcrews, which paſſing through the ring in different parts of its circumference all point towards its center.

The carriage, together with the barrel, was ſuſpended by the pendulous rods by means of two pair of poliſhed trunnions that are fixed to the outſide of the carriage. They are placed in an horizontal line perpendicular to, and paſſing through, the axis of the bore.

Fig. 8. repreſents the barrel fixed to the carriage.

a, *b*, *c*, is the bar of iron which forms the carriage ſeen edge-ways.

2, 2, 4, 4, are the trunnions by which it was ſuſpended.

d, *e*, is the barrel in its proper place.

p, is the breech-pin, which paſſing through a hole in the middle of the bar, *a*, *b*, *c*, ſupports the end, *e*, of the barrel; and

n, is the ring that ſupports the end, *d*, of the barrel.

Fig.

Fig. 9. repreſents a perpendicular ſection through the line 2, 2, fig. 8. and in a line perpendicular to the length of the barrel.

This figure is deſigned to ſhew the manner in which the muzzle of the piece was ſupported and confined in the ring *n*, fig. 8.

a, *c*, are the two ends of the bar that are ſeen cut off.

n, is the ring, and

o, *p*, are the ſcrews by which it is faſtened to the two parallel ſides of the bar, the ends of which form the trunnions 2, 2, fig. 8.

d, is a tranſverſe ſection of the barrel, and

r, *s*, *t*, are the three ſcrews by which the barrel is ſupported and confined in the center of the ring.

Fig. 10. is the ſame as fig. 9. but upon a larger ſcale.

Fig. 11. repreſents the two ends of one of the pendulous rods by which the barrel was ſuſpended; and fig. 13. ſhews the ſame ſeen ſideways.

a, *b*, is the rod which is ſeen broken off.

c, *d*, are the pivots by which it was ſuſpended by a pair of hooks or grooves that were faſtened to an horizontal beam, in the ſame manner as the pendulum for meaſuring the velocities of the bullets was ſuſpended.

e, *f*, are the hooks which receive the trunnions that are fixed to the carriage.

The dimenſions of every part of this apparatus may be ſeen in the table, p. 242.

The chord of the arc through which the barrel aſcended in its recoil was meaſured by a ribbon, and the lengths of thoſe chords, expreſſed in inches and decimal parts of an inch, are ſet down in the tables. The method of computing the velocity of the recoil from the chord of the arc through which the barrel aſcended, is too well known to require an explanation: and it is alſo well known, that the velocities are to each other as the chords of thoſe arcs. The lengths of thoſe chords, therefore, as they are ſet down in the tables, are, in all caſes, as the velocities of the recoil.

The powder made uſe of in theſe experiments was of the beſt kind, ſuch as is uſed in proving great guns at Woolwich. A cartridge, containing 12 lbs. of this powder, was given to me by the late General DESAGULIERS of the Royal Artillery, and Inſpector of Braſs and Iron Ordnance; who alſo, in the politeſt manner, offered me every other aſſiſtance in his power towards completing the experiments I had projected, or in making any others I ſhould propoſe that might be uſeful in the proſecution of my inquiries.

This powder was immediately taken out of the cartridge, and put into glaſs bottles, which were previouſly made very clean and dry; and in theſe it was kept carefully ſealed up till it was opened for uſe. When it was wanted for the experiments, it was weighed out in a very exact balance, with ſo much attention, that there could not poſſibly be an error in any inſtance greater than one quarter part of a grain. The bottles were never opened but in fine weather, and in a room that was free from damp, and no more charges of powder than were neceſſary for the experiments of the day were weighed out at a time. Each charge was carefully put up in a cartridge of very fine paper, and theſe filled cartridges were kept in a turned wooden box, that was varniſhed on the inſide as well as the outſide, to prevent its imbibing moiſture from the air.

The paper of which theſe cartridges were made was ſo fine and thin, that 1280 ſheets of it made no more than an inch in thickneſs, and a cartridge capable of containing half an ounce of powder weighed but three quarters of a grain.

The cartridges were formed upon a wooden cylinder, and accurately fitted to the bore of the piece, and the edges of the paper were faſtened together with paſte made of flour and water.

When a cartridge was filled, the powder was gently ſhaken together, and its mouth was tied up and ſecured with a piece of fine thread; and when it was made uſe of it was put intire into the piece, and gently puſhed down into its place with the ramrod, and afterwards it was pricked with a priming-wire thruſt through the vent, and the piece was primed; ſo that no part of the powder of the charge was loſt in the act of loading, as is always the caſe when the powder is put looſe into the barrel: nor was any part of it expended in priming; but the whole quantity was ſafely lodged in the bottom of the bore or chamber of the piece, and the bullet was put down immediately upon it, without any wadding either between the cartridge and the bullet, or over the bullet.

The bullets were all caſt in the ſame mould, and conſequently could not vary in their weights above two or three grains at moſt, eſpecially as I took care to bring the mould to a proper temperature as to heat before I began caſting; and when leather was put about them, or other bullets than thoſe of lead were made uſe of, the weight was determined very exactly before they were put into the piece.

The diameter of the bullet was determined by meaſurement and alſo by computation from its weight, and the ſpecfic gravity of the metal of which it was formed; and both theſe methods gave the ſame dimenſions very nearly.

The apparatus was put up for making the experiments in a coach-houſe, which was found very convenient for the purpoſe, as the joiſts upon which the floor over head was laid afforded a firm and commodious ſupport for ſuſpending the pendulum and the barrel, and the walls and roofs of the building ſerved to ſcreen the apparatus, which otherwiſe might have been diſcompoſed by the wind, and injured by the rain and dews. A pair of very large doors, which formed the whole of one end of the room, were kept conſtantly open during the time the experiments were making, in order to preſerve the purity of the air within the houſe, which otherwiſe would have been much injured by the ſmoke of the gun-powder; and that, in all probability, would have had a conſiderable effect in leſſening the force of the powder, and vitiating the experiments. In order ſtill further to guard againſt this evil, the barrel was placed as near as poſſible to the door, and the pendulum was hung up at the bottom of the room.

Fig. 12. repreſents the apparatus as it was put up for making the experiments.

a, *b*, is the barrel with its carriage, ſuſpended by the pendulous rods *c*, *d*, and

R, is the ribbon which ſerved to meaſure the aſcending arc of its recoil.

P, is the pendulum, and

r, the ribbon that meaſured the arc of its vibration.

The diſtance from the mouth of the piece to the pendulum was juſt 12 feet.

A table ſhewing the weights and dimenſions of all the principal parts of the apparatus.

Of the barrel.

	Inches.
Length	44,7
Length of the bore from the muzzle to the breech-pin	43,45
Diameter of the bore	0,78
Thickneſs of metal at the lower vent	0,36
Thickneſs of metal at the muzzle	0,1

Weight of the barrel, together with the ſolid breech-pin, and the vent-ſcrews and vent-tube, 6 lbs. 6 oz.

Of the gun carriage.

Length	28,4
Diſtance between the two pair of trunnions	25,6
Diameter of each trunnion	0,25

Weight 40 lbs. 14 oz.

Of the rods by which the carriage was ſuſpended.

Length from the axis of ſuſpenſion, or center of the pivots, to the center of the trunnions of the gun carriage, 64 inches.

Weight of each rod, 1 lb. 4 oz.

Total weight of the barrel and its carriage, together with the allowance that was made for the weight of the rods by which it was ſuſpended, 48 lbs.

N. B. This was its weight from experiment N° 3. to experiment N° 123. incluſive.

Of

Of the bullet.

Diameter 0,75 of an inch.
Weight in lead 580 grains.

Of the pendulum.

	Inches.
Total length of the pendulum from the axis of ſuſpenſion to the bottom of the circular plate .	69,5
Diameter of the circular plate to which the targets were faſtened	13,–
Diſtance between the ſhoulders of the pivots .	3,8
Diameter of the pivots . . .	,27

Weight of the iron part of the pendulum 47 lb. 4 oz.

Of the pendulum with the targets fixed to it, as it was prepared for making the experiments, and numbered.

	Total length to the ribbon.	Diſtance from the axis of ſuſpenſion.		Total weight of iron and wood.	
		To the center of gravity.	To the center of oſcillation.		
	Inches.	Inches.	Inches.	lbs.	oz.
Pendulum N° 1	69,25	50,25	58,45	57	0
——— N° 2	69,5	54,4	59,15	82	4
——— N° 3	——	55,62	60,23	100	12
——— N° 4	——	54,6	59,18	88	4

N. B. The meaſure is Engliſh feet and inches, and the weight is avoirdupois.

Having now gone through the deſcription of all the principal parts of the apparatus, I ſhall proceed to give an account of the experiments. And as it may be ſatisfactory to the Society to ſee the method of conducting theſe enquiries, as well as the reſult of them, I ſhall firſt give a table of the experiments in the exact order in which they were made, together with my original remarks; I ſhall then make ſuch general obſervations as may occur: and afterwards I ſhall ſelect, combine, and compare them, in the manner which beſt anſwers the different purpoſes to which I ſhall apply them.

General table of the experiments.

In the two firſt experiments the barrel was fixed to a carriage (that has not been deſcribed) which, together with the barrel and rods by which it was ſuſpended, weighed only 23½.

Length of the bore of the piece 43,5 inches.
Weight of the bullet 580 grains.

The pendulum, N° 1.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	The bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	Grs.	In.	In.	Inches.	Inches.	In.	Ft. in Sec.	
N° 1	208	1,8	0,	13,2	64,5	33,5	1267	Firſt day.
2	. .	. .	,5	14,5	. . .	36,5	1399	

This gun carriage being found to be too light, the other, deſcribed, and repreſented fig. 8. was ſubſtituted in the room of it.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	The bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in sec.	
N° 3	208	1,8	0	12,6	65,	17,8	1213	Second day.
4	. .	. .	,5	——	——	18,5	—	The pendulum gave way.
5	. .	. .	0	——	——	38,68	—	4 bullets were fired at once.
6	. .	. .	,5	——	——	38,48	—	Ditto.
7	. .	. .	0	——	——	6,1	—	Without any bullet.
8	416	3,6	. .	——	——	16,5	—	Ditto.
9	208	1,8	0	8,5	65,	17,69	1281	Pen. N° 2; very fair; 3d day.
10	104	,9	. .	5,2	65,25	10,18	782	
11	310	2,7	0	9,6	64,6	24,69	1459	The powder was lighted by the long vent-tube (fig. 4.).
12	. .	. .	1,22	10,1	65,	24,95	1527	
13	. .	. .	2,65	11,85	64,75	24,9	1801	
14	. .	. .	. .	10,9	65,25	. . .	1646	
15	330	2,9	2,65	10,9	61,5	26,2	1748	
16	. .	. .	. .	13,25	63,5	. . .	2060	
17	330	2,7	2,65	. . .	. . .	12,7	. .	The barrel very much heated.
18	. .	2,9	0	10,4	63,5	26,3	1619	
19	. .	. .	. .	. . .	63,	26,4	1633	
20	165	1,45	0	6,8	62,2	14,73	1084	
21	. .	. .	. .	6,85	. . .	14,2	1093	
22	. .	. .	1,32	6,7	. . .	14,8	1071	
23	. .	. .	. .	6 3	60,6	14,58	1035	The ſhort vent-tube (*v*, fig. 3.) was made uſe of.
24	. .	. .	. .	7,5	61,5	14,68	1142	

In order to determine how much of the force of the powder was loſt by windage and by the vent, oiled leather was faſtened round the bullet, ſo that it now accurately fitted the bore of the piece; and in the five experiments, from N° 35. to N° 39. incluſive, the valve-vent was made uſe of.

Weight of the bullet, together with the leather in which it was enveloped, 603 grains.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	The bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N°	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in ſec.	
25	165	1,45	0	6,8	65,	14,95	1004	Fourth day.
26	. .	. .	. .	7,8	. . .	15,6	1153	
27	. .	. .	. .	8,05	. . .	16,15	1192	
28	330	2,9	. .	10,2	63,	26,	1559	
29	. .	. .	2,6	. . .	64,	28,1	1536	
30	165	3,2	. .	5,9	62,4	13,2	914	
31	. .	1,45	1,3	6,65	62,6	15,15	1027	

Finding that the blaſt of the powder always reached as far as the pendulum, when large charges were made uſe of, and ſuſpecting that this circumſtance, together with the impulſe of the unfired grains, might in a great meaſure occaſion the apparent irregularity in the velocities of the bullets; to remedy theſe inconveniences, a large ſheet of paper of a moderate thickneſs was ſtretched upon a ſquare frame of wood, and interpoſed as a ſcreen before the pendulum at the diſtance of two feet from the ſurface of the target.

Two reaſons conſpired to induce me to prefer this method of preventing the impulſe of the flame upon the pendulum to the obvious one of removing the pendulum further from the mouth of the piece; the firſt was, that I was unwilling to increaſe the diſtance between the barrel and the pendulum, leſt the reſiſtance of the air might affect the velocities of the bullets; and the ſecond, which I confeſs did not operate leſs ſtrongly than the firſt, was, that the length of the houſe did not admit of a greater

diſtance,

diſtance, and I was unwilling to expoſe any part of the apparatus in the open air.

But the ſcreen was found to anſwer perfectly well the purpoſe for which it was deſigned, and it was continued during the remainder of the experiments, the paper being replaced every third or fourth experiment.

The experiments continued.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	Bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N°	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in ſec.	
32	165	1,45	0	5,45	63,	15,45	839	Not leathered; weight of the bullet and wad 603 grs. In exp. N° 32. no leſs than 40 large grs. of unfired powder were driven through the ſcreen.
33	. .	. .	. .	. . .	. . .	12,65	839	
34	. .	. .	. .	7,9	. . .	15,45	1217	In theſe 6 experiments the bullets were leathered, and the powder was lighted by the valve-vent. The pend. N° 2. ruined.
35	. .	. .	. .	7,	60,25	15,25	1129	
36	. .	. .	. .	7,4	62,	16,3	1161	
37	. .	. .	1,3	8,	61,	17,9	1277	
38	290	2,6	2,6	9,	58,6	23,5	1497	
39	. .	. .	. .	. . .	. . .	24.8	. .	

The bullets were now put naked into the piece, and the powder was lighted by the ſhort vent-tube (*v*, fig. 3) and ſome little improvement was made in the ſteel edges between which the ribbons paſſed that ſerved to meaſure the aſcending arcs of the pendulum and of the recoil, by which means the friction was leſſened, and the ribbon was prevented from twiſting or entangling itſelf as it was drawn out.

Apparatus.

The barrel with its carriage as before.
The pendulum, N° 3. and
Leaden bullets, weighing 580 grains each.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	Bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N°	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in ſec.	
40	218	1,9	0	6,45	64,6	18,	1236	5th day; medium velocity in theſe experiments and N° 47. 1225.
41	. .	. .	. .	6,31	65,3	17,71	1197	
42	. .	. .	. .	6,45	65,	17,91	1230	
43	. .	. .	1,3	6,5	64,6	18,3	1248	Medium velocity 1276
44	. .	. .	. .	6,75	64,5	18,35	1299	
45	. .	. .	. .	6,6	64,9	. . .	1265	
46	. .	. .	. .	6,4	61,6	. . .	1293	
47	. .	. .	0,	6,3	62,	18,1	1266	
48	290	2,6	0	7,2	63,5	22,58	1414	Medium velocity 1427.
49	. .	. .	. .	7,4	. . .	22,92	1455	
50	. .	. .	. .	7,3	64,6	22,38	1412	
51	290	2,6	1,3	7,4	63,	23,21	1476	Medium velocity 1493.
52	. .	. .	. .	7,6	64,	23,76	1520	
53	. .	. .	. .	7,25	61,	23,6	1483	
54	. .	. .	2,6	7,5	62,3	. . .	1502	Medium velocity 1460.
55	. .	. .	. .	7,4	64,	23,26	1450	
56	. .	. .	. .	7,1	62,2	. . .	1433	
57	. .	. .	. .	7,4	64,	23.56	1454	
58	. .	. .	. .	1,31		11,12	—	In theſe 4 experiments the piece was fired with powder alone, and the ſcreen was taken away from before the pendulum.
59	. .	. .	. .	1,2		11,62	—	
60	. .	. .	0	1,16		9,62	—	
61	. .	. .	1,3	0,6		11,33	—	

Order

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	Bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N°	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in ſec.	
62	330	2,9	1,3	8,	63,	26,4	1599	6th day; medium velocity 1625.
63	. .	. .	. .	8,5	65,	. . .	1652	
64	. .	. .	2,6	7,2	59,5	25,3	1562	Medium velocity 1528.
65	. .	. .	. .	7,7	65,	. . .	1495	
66	. .	. .	0	8,4	. . .	26,35	1633	Medium velocity 1594.
67	. .	. .	. .	8,	. . .	25,8	1556	
68	218	1,9	0	6,82	64,	19,56	1349	The powder was rammed very hard.
69	. .	. .	. .	6,6	64,6	18,2	1294	Ditto much harder.
70	. .	. .	. .	6,85	. . .	19,12	1345	Ditto as hard as in N° 68.
71	. .	. .	1,3	5,5	. . .	16,33	1080	Ditto, ditto.
72	. .	. .	0	——	——	8,72	—	Government powder, no bullet.
73	. .	. .	. .	——	——	8,44	—	Beſt double battle powder.
74	. .	. .	1,3	——	——	8,47	—	Government powder.
75	. .	. .	. .	——	——	9,3	—	Double battle powder.

The following experiments N° 78, 79, 80, and 81. were made in hopes of being able to diſcover a method of adding to the force of gun-powder. Twenty grains of the ſubſtances mentioned in the remarks upon each experiment were intimately mixed with the powder of the charge. In the experiment N° 82. a large wad of tow, well ſoaked in etherial ſpirit of turpentine, was put into the piece immediately upon the bullet: and in the experiment N° 83. a wad, ſoaked in alkohol, was put into the piece in like manner.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	Bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
N°	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in ſec.	
76	145	1,3	0	5,3	65,	13,25	1037	7th day; medium velocity 1040.
77	. .	. .	. .	. . .	64,6	13,25	1044	
78	. .	. .	. .	3,2	. . .	8 92		20 grs. beſt alkaline ſalt of tartar.
79	. .	. .	. .	4,35	. . .	11,68		20 grs. æthiops mineral.
80	. .	. .	. .	3,3	63,6	9,83		20 grs. ſal ammon.
81	. .	. .	. .	4,2	63,4	11,45		20 grs. fine braſs duſt.
82	. .	. .	. .	——	——	15,25	—	The ſcrews which held the hooks by which the pendulum was ſuſpended gave way, and the pendulum came down.
83	. .	. .	. .	——	——	14,35	—	

In the nine following experiments, *viz.* from N° 84. to N° 92. incluſive, the valve-vent was made uſe of, and the bullets were made to fit the bore of the piece very exactly by means of oiled leather, which was ſo firmly faſtened about them that in each experiment it entered the target with the bullet.

The bullet made uſe of in experiment N° 85. was of wood.

Thoſe uſed in the experiments N° 86. and N° 87. were formed in the following manner; a ſmall bullet was caſt of plaiſter of Paris, which being thoroughly dried, and well heated at the fire, was fixed in the center of the mould that ſerved for caſting all the leaden bullets made uſe of in theſe experiments; and melted lead being poured into this mould, the cavity that ſurrounded the ſmall plaiſter bullet was intirely filled up, and a bullet was produced, which to the eye had every appearance of ſolidity, but was as much lighter than a ſolid leaden bullet of the ſame diameter as the plaiſter bullet was lighter than a leaden bullet of the ſame ſize.

In the experiments N° 88. and N° 89. ſolid leaden bullets were made uſe of. In the experiment N° 90. two bullets were diſcharged at once; in the experiment N° 91. three; and in the experiment N° 92. four were uſed.

In each of theſe experiments a freſh ſheet of paper was made uſe of as a ſcreen to the pendulum, in order that the velocities of the bullets might be meaſured more accurately; and alſo, that the quantity of unfired powder might be eſtimated with greater preciſion.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Weight of the bullet.	Chord of the aſcending arc of the pendulum.	Bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.							
	Grs.	In.	In.	Grs.	Inches.	Inches.	Inches.	Ft. in fec.	
N° 84	145	1,3	0	—	——	——	4,5	—	8th day; in each of theſe 4 experiments from 50 to 70 granulæ or particles of unfired powder were driven through the ſcreen.
85	. .	. .	. .	90	1,33	62,2	7,16	1763	
86	. .	. .	. .	251	2,82	63,2	9,62	1317	
87	. .	. .	. .	354	3,32	61,2	11,3	1136	
88	. .	. .	. .	600	6,5	65,4	15,22	1229	Very few unfired grains of powder ſtruck the ſcreen.
89	. .	. .	. .	603	6,3	64,6	15,13	1229	
90	. .	. .	. .	1184	10,12	65,	21,92	978	There were no marks of any unfired powder having reached the ſcreen.
91	. .	. .	. .	1754	13,65	63,4	27,18	916	
92	. .	. .	. .	2352	16,55	63·3	32,25	833	

In the ſeven following experiments the piece was fired with powder only.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	Chord of the arc of the recoil.	Remarks.
	Weight	Height.				
	Grs.	In.	In.	Inches.	Inches.	
N°						
93	145	1,3	0	——	4,3	
94	165	1,45	. .	——	5,5	
95	. .	. .	. .	——	5,6	
96	290	2,6	. .	——	11,70	
97	437½	3,9	. .	1,68	17,5	The ſcreen was taken away.
98	. .	. .	. .	6,7	15,88	The whole ſurface of the target was beſpattered with unfired grains of powder.
99	. .	. .	. .	——	17,9	The pendulum was not obſerved.

In the following experiments N° 100. and N° 101. the bullets were not put down into the bore, but were ſupported by three wires, which being faſtened to the end of the barrel projected beyond it, and confined the bullet in ſuch a ſituation that its center was in a line with the axis of the bore, and its hinder part was one-twentieth of an inch without or beyond the mouth of the piece.

In experiment N° 102. the bullet was juſt ſtuck into the barrel in ſuch a manner that near one-half of it was without the bore.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	Bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	Grs.	In.	In.	Inches.	Inches.	Inches.	Ft. in ſec.	
N° 100	165	1,45	0	,65	60,5	4,9	138	In each of theſe experim. near $\frac{1}{10}$th part of the ſubſtance of the bullet was melted and blown away by the impulſe of the flame.
101	. .	. .	. .	,43	uncertain.	4,8	92	
102	. .	. .	. .	,86	63,	5,6	180	

All that part of the bullet which lay towards the bore of the piece appeared to be quite flat from the loſs of ſubſtance it had ſuſtained; and its ſurface was full of ſmall indents, which probably were occaſioned by the unfired grains of powder that impinged againſt it.

The following experiments were made with the pendulum N° 4. The reſt of the apparatus as before.

Order of the experiments.	The charge of powder.		Vent from the bottom of the charge.	Chord of the aſcending arc of the pendulum.	Bullet ſtruck the target below the axis of the pendulum.	Chord of the arc of the recoil.	Velocity of the bullet.	Remarks.
	Weight.	Height.						
	In.	In.	In.	Inches.	Inches.	Inches.	Ft. in ſec.	
N°								9th day.
103	104	,9	0	4,51	65,	10,6	732	About 40 grains of powder were driven through the ſcreen.
104	145	1,3	. .	5,4	. . .	12,92	877	About 40 unfired grs. of powder. Medium velocity 894. 40 unfired grains.
105	. .	. .	. .	5,6	. . .	13,28	910	
106	. .	1,14	. .	6,18	65,8	14,3	990	Double proof battle powder; no unfired grains.
107	218	1,8	. .	8,48	65,	19,68	1380	Ditto, ditto.
108	290	2,6	. .	9,45	65,6	23,9	1526	Government powder; bullet leathered; weight 602 grains.
109	. .	. .	. .	8,73	65,2	22,8	1419	Bullet naked; very few unfired grains. Medium velocity 1444.
110	. .	. .	. .	9,3	65,6	23,4	1460	
111	. .	. .	. .	. . .	. . .	. . .	1462	
112	. .	. .	. .	8,85	65,5	22,94	1436	
113	. .	. .	2,6	8,65	64,	23,7	1438	Medium velocity 1413.
114	. .	. .	. .	8,5	63,6	24,1	1423	
115	. .	. .	. .	8,4	65,	23,8	1378	
116	. .	2,28	. .	9,15	64,	24,6	1525	Double proof battle powder.
117	437½	3,9	. .	10,56	64,9	33,	1738	Gov. pow. No unfired grains thro' the ſcreen. Medium velocity 1764.
118	. .	. .	. .	11,	64,5	33,3	1824	
119	. .	. .	. .	10,5	65,	33,6	1729	
120	. .	. .	2,6	10,35	. . .	32,5	1706	Medium velocity 1751.
121	. .	. .	. .	10,65	. . .	33,2	1757	
122	. .	. .	. .	10,6	63,6	32,9	1789	
123	. .	. .	0	——	——	17,9	—	Without any bullet.

Of

Of the method made uſe of for computing the velocities of the bullets.

As the method of computing the velocity of a bullet from the arc of the vibration of a pendulum into which it is fired is ſo well known, I ſhall not enlarge upon it in this place, but ſhall juſt give the theorems that have been propoſed by different authors, and ſhall refer thoſe who wiſh to ſee more on the ſubject to Mr. ROBINS's New Principles of Gunnery; to Profeſſor EULER's Obſervations upon Mr. ROBINS's Book; and, laſtly, to Dr. HUTTON's Paper on the initial Velocities of Cannon Balls, which is publiſhed in the Tranſactions of the Society for the year 1778.

If a denote the length from the axis of the pendulum to the ribbon which meaſures the chord of the arc of its vibration;

g, the diſtance of the center of gravity below the axis;

f, the diſtance of the center of oſcillation;

h, the diſtance of the point ſtruck by the bullet;

c, the chord of the aſcending arc of the pendulum;

P, the weight of the pendulum;

b, the weight of the bullet, and

v, the original velocity of the bullet;

$v=\frac{c}{a}\times\overline{\frac{Pg}{bh}+\frac{h}{f}}\times\frac{f}{\sqrt{2h}}$, is a theorem for finding the velocity upon Mr. ROBINS's principles.

*$v=\frac{c}{a}\times\overline{\frac{Pg}{bh}+\frac{f+h}{2f}}\times\sqrt{\frac{f}{2}}$, is the theorem propoſed by Profeſſor EULER, who has corrected a ſmall error in Mr. ROBINS's method; and

$v=$

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* Put the rational part $\frac{c}{a}\times\overline{\frac{Pg}{bh}+\frac{f+h}{2f}}=n$, and expreſs f in the thouſandth parts of a Rhynland foot; then the velocity with which the ball ſtrikes the pendulum will be $=\frac{n}{4}\sqrt{\frac{f}{2}}$ Rhynland feet in a ſecond.

$v = 5{,}672\, cg\sqrt{f} \times \frac{P+b}{bha}$ is Dr. HUTTON's theorem, which is ſufficiently accurate, and far more ſimple and expeditious than either of the preceding. It is to be remembered, that g, h, and c, may be expreſſed in any meaſure; but f muſt be Engliſh feet, and v will be the velocity of the bullet in Engliſh feet in a ſecond.

The velocities of the bullets in moſt of the foregoing experiments were firſt computed by EULER's method, as I had not then ſeen Dr. HUTTON's paper; but in going over the calculations a ſecond time, I made uſe of Dr. HUTTON's theorem. Both theſe methods gave the ſame velocity very nearly, but the Doctor's method is by much the eaſieſt in practice.

In theſe computations care was taken to make a proper allowance for the bullets that were lodged in the pendulum, and alſo for the velocity loſt by the bullet in paſſing through the ſcreen.

The corrections neceſſary on account of the bullets lodged in the pendulum were made in the following manner.

b was continually added to the value of P,

$\frac{h-g}{P} \times b$ . . . to the value of g, and

$\frac{f-h}{P} \times b$ . . . to the value of f.

Of the ſpaces occupied by the different charges of powder.

The heights of the charges of powder, or the lengths of the ſpaces which they occupied in the bore, were determined by meaſurement; and in order that this might be done with greater accuracy, inches and tenths of inches were marked upon the ram-rod, and the charge was gently forced down till it occupied the ſame ſpace in each experiment.

The following table ſhews the heights of the charges as they were determined by meaſurement, and alſo their heights computed from the diameter of the bore of the piece, and the ſpecific gravity of the powder that was made uſe of.

N. B. By an experiment I ſhall give an account of hereafter, I found the ſpecific gravity of this powder ſhaken well together to be to that of rain water as 0,937 is to 1,000.

Weight of the powder.	Height of the charge.	
	Meaſured.	Computed.
Grs.	Inches.	Inches.
104	,9	0,8957
145	1,3	1,2490
165	1,45	1,4211
208	1,8	1,7914
218	1,9	1,8775
290	2,6	2,4980
310	2,7	2,6700
330	2,9	2,8422
416	3,6	3,5828
437½	3,9	3,7680

In the experiment N° 30. the powder was put into a cartridge ſo much ſmaller than the bore of the piece, that the charge, inſtead of occupying 1,45 inches, extended 3,2 inches. By this diſpoſition of the powder, its action upon the bullet appears to have been very much diminiſhed.

Of the effect that the heat which pieces acquire in firing produces upon the force of powder.

It is very probable, that the exceſs of the velocity of the bullet in the ſecond experiment over that of the firſt was occaſioned more by the heat the barrel had acquired in the firſt experiment than by the poſition of the vent, or any other circumſtance; for I have ſince found, upon repeated trials, that the force of any given charge of powder is conſiderably greater when it is fired in a piece that has been previouſly heated by firing, or by any other means, than when the piece has not been heated. Every body that is acquainted with artillery knows, that the recoil of great guns is much more violent after the ſecond or third diſcharge than it is at firſt; and on ſhip-board, where it is neceſſary to attend to the recoil of the guns, in order to prevent very dangerous accidents that might be occaſioned by it, the conſtant practice has been in our navy, and, I believe, on board the ſhips of all other nations, to leſſen the quantity of powder after the firſt four or five rounds: our 32 pounders, for inſtance, are commonly fired with 14 lbs. of powder at the beginning of an action, but the charge is very ſoon reduced to 11 lbs. and afterwards to 9 lbs. and the filled cartridges are prepared accordingly.

By the recoil it ſhould ſeem, that the powder exerted a greater force alſo in the fourth experiment, being the ſecond upon the ſecond day, than it did upon the third, or the firſt upon that day; but the pendulum giving way, it was not poſſible to compare the velocities of the bullets in the manner we did in the two experiments mentioned above.

This augmentation of the force of powder, when it is fired in a piece that is warm, may be accounted for in the following manner. There is no ſubſtance we are acquainted with that does not require to be heated before it will burn; even gunpowder is not inflammable when it is cold. Great numbers of ſparks or red-hot particles from the flint and ſteel are frequently ſeen to light upon the priming of a muſket, without ſetting fire to the powder, and grains of powder may be made to paſs through the flame of a candle without taking the fire; and what is ſtill more extraordinary, if large grains of powder are let fall from the height of two or three feet upon a red-hot plate of iron, laid at an angle of about 45° with the plane of the horizon, they will rebound intire without being burnt, or in the leaſt altered, by the experiment. In all theſe caſes the fire is too feeble, or the duration of its action is not ſufficiently long to heat the powder to that degree which is neceſſary in order to its being rendered inflammable.

Now as gun-powder, as well as all other bodies, acquires heat by degrees, and as ſome ſpace of time is taken up in this as well as in all other operations, it follows, that powder, which has been warmed by being put into a piece made hot by repeated firing, is much nearer that ſtate in which it will burn, or, I may ſay, is more inflammable than powder which is cold; conſequently, more of it will take fire in a given ſhort ſpace of time, and its action upon the bullet and upon the gun will of courſe be greater.

The heat of the piece will alſo ſerve to dry the air in the bore, and to clear the inſide of the gun of the moiſture that collects there when it has not been fired for ſome time, and theſe circumſtances doubtleſs contribute ſomething to the quickneſs of the inflammation of the powder, and conſequently to its force.

As it takes a longer time to heat a large body than a ſmall one, it follows, that meal-powder is more inflammable than that which is grained; and the ſmaller the particles are, the quicker they will take fire. The ſailors bruiſe the priming after they have put it to their guns, as they find it very difficult, without this precaution, to fire them off with a match: and if thoſe who are fond of ſporting would make uſe of a ſimilar artifice, and prime their pieces with meal-powder, they would miſs fire leſs often, the ſprings of the lock might be made more tender, and its ſize conſiderably reduced without any riſque, and the violence of the blow of the flint and ſteel in ſtriking fire being leſſened, the piece might be fired with greater preciſion.

Concluding from the reſult of the four experiments mentioned above, as well as from the reaſons juſt cited, that the temperature of the piece has a conſiderable effect upon the force of the powder, I afterwards took care to bring the barrel to a proper degree of heat, by firing it once or oftener with powder each time I recommenced the experiments after the piece had been left to cool.

Of the manner in which pieces acquire heat in firing.

I was much ſurpriſed upon taking hold of the barrel immediately after the experiment N° 17. when it was fired with 330 grains of powder without any bullet, to find it ſo very hot that I could ſcarcely bear it in my hand, evidently much hotter than I had ever obſerved it before, notwithſtanding the ſame charge of powder had been made uſe of in the two preceding experiments, and in both theſe experiments the piece was loaded with a bullet, which one would naturally imagine, by confining the flame, and prolonging the time of its action, would heat the barrel much more than when it was fired with powder alone.

I was convinced that I could not be miſtaken in the fact, for it had been my conſtant practice to take hold of the piece to wipe it out as ſoon as an experiment was finiſhed, and I never before had found any inconvenience from the heat in holding it. But in order to put the matter beyond all doubt, after letting the barrel cool down to the proper temperature, I repeated the experiment twice with the ſame charge of powder and a bullet; and in both theſe trials (experiments N° 18. and N° 19.) the heat of the piece was evidently much leſs than what it was in the experiment above mentioned (N° 17.).

I now regretted exceedingly the loſs of a ſmall pocket thermometer, which I had provided on purpoſe to meaſure the heat of the barrel, but it was accidentally broken by a fall the day before I began my experiments; and being ſo far from London, I had it not in my power to procure another: I was therefore obliged to content myſelf with determining the heat of the piece as well as I could by the touch.

Being much ſtruck with this accidental diſcovery of the great degree of heat that pieces acquire when they are fired with powder without any bullet, and being deſirous of finding out whether it is a circumſtance that obtains univerſally, I was very attentive to the heat of the barrel after each of the ſucceeding experiments; and I conſtantly found the heat ſenſibly greater when the piece was fired with powder only, than when the ſame charge was made to impel one or more bullets.

Though the reſult of theſe experiments was totally unexpected, and even contrary to what I ſhould have foretold if I had been aſked an opinion upon the ſubject previous to making them; yet, after mature conſideration, I am now convinced, that it is what ought to happen, and that it may be accounted for very well upon principles that are clearly admiſſible.

It is certain, that a very ſmall part only of the heat that a piece of ordnance acquires in being fired is communicated to it by the flame of the powder; for the time of its action is ſo ſhort (not being, perhaps, in general longer than about $\frac{1}{200}$th or $\frac{1}{150}$th part of a ſecond) that if its heat, inſtead of being 4 times, as Mr. ROBINS ſuppoſes, was 400 times hotter than red-hot iron, it could not ſenſibly warm ſo large a body of metal as goes to form one of our large pieces of cannon. And beſides, if the heat of the flame was ſufficiently intenſe to produce ſo great an effect in ſo ſhort a time, it would certainly be ſufficient to burn up all inflammable bodies that it came near, and to melt the ſhot that it ſurrounded and impelled, eſpecially when they were ſmall, and were compoſed of lead or any other ſoft metal; but, on the contrary, we frequently ſee the fineſt paper come out of the mouth of a piece uninflamed, after it has ſuſtained the action of the fire through the whole length of the bore, and the ſmalleſt lead ſhot is diſcharged without being melted.

But it may be objected here, that bullets are always found to be very hot if they are taken up immediately after they come out of a gun; and that this circumſtance is a proof of the intenſity of the heat of the flame of powder, and of its great power of communicating heat to the denſeſt bodies. But to this I anſwer, I have always obſerved the ſame thing of bullets diſcharged from wind-guns and croſs-bows, eſpecially when they have impinged againſt any hard body, and are much flattened; and bullets from muſkets are always found to be hotter in proportion to the hardneſs of the body againſt which they are fired. If a muſket ball is fired into any very ſoft body, as (for inſtance) into water, it will not be found to be ſenſibly warmed; but if it is fired againſt a thick plate of iron, or any other body that it cannot penetrate, the bullet will be demoliſhed by the blow, and the pieces of it that are diſperſed about will be found to be in a ſtate very little ſhort of fuſion, as I have often found by experience. It is not by the flame therefore that bullets are heated, but by percuſſion. They may, indeed, receive ſome ſmall degree of warmth from the flame, and ſtill more perhaps by friction againſt the ſides of the bore, but it is in ſtriking againſt hard bodies, and from the reſiſtance they meet with in penetrating thoſe that are ſofter, that they acquire by far

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the greater part of the heat we find in them as ſoon as they come to be at reſt, after having been diſcharged from a gun.

There is another circumſtance that may poſſibly be brought as an objection to this opinion, and that is the running of the metal in braſs guns upon repeatedly firing them, by which means the vent is often ſo far enlarged as to render the piece intirely uſeleſs. But this, I think, proves nothing but that braſs is very eaſily corroded, and deſtroyed by the flame of gun-powder; for it cannot be ſuppoſed, that in theſe caſes the metal is ever fairly melted. The vent of a muſket is very ſoon enlarged by firing, and after a long courſe of ſervice it is found neceſſary to ſtop it up with a ſolid ſcrew, through the center of which a new vent is made of the proper dimenſions. This operation is called buſhing, or rather bouching the piece; but in all the better kind of fowling-pieces the vent is lined, or bouched, with gold, and they are found to ſtand fire for any length of time without receiving the leaſt injury. But every body knows that gold will run with a leſs heat than is required to melt iron: but gold is not corroded either by the ſpirit of nitre, or the acid ſpirit that is generated from ſulphur, whereas iron is very eaſily deſtroyed by either; and that I take to be the only reaſon why a vent that is lined with gold is ſo much more durable than one that is made in iron. But it ſeems, that iron is more durable than braſs; and perhaps ſteel, or ſome other cheap metal, may be found that will ſupply the place of gold, and by that means the great expence that attends bouching pieces with that precious metal may be ſpared, and this improvement may be introduced into common uſe.

This leads us to a very eaſy and effectual remedy for that defect ſo long complained of in all kinds of braſs ordnance, *the running of the vent*; for if theſe pieces were bouched with iron, there is no doubt but they would ſtand fire as well as iron guns; and if ſteel, or any other metal, either ſimple or compounded, ſhould upon trial be found to anſwer for that purpoſe better than iron, it might be uſed inſtead of it; and even if gold was made uſe of for lining the vent, I imagine it might be done in ſuch a manner as that the expence would not be very conſiderable, at the ſame time that the thickneſs of the gold ſhould be ſufficient to withſtand the force of the flame for a very great length of time.

But to return to the heat acquired by guns in firing. It being pretty evident that it is not all communicated by the flame, there is but one other cauſe to which it can be attributed, and that is the motion and friction of the internal parts of the metal among themſelves, occaſioned by the ſudden and violent effort of the powder upon the inſide of the bore, and to this cauſe I imagine the heat is principally if not almoſt intirely owing. It is well known, that a very great degree of heat may be generated in any hard and denſe body in a ſhort ſpace of time by friction, and in a ſtill ſhorter time by colliſion. "For if two denſe hard elaſtic bodies be ſtruck againſt "each other with great force and velocity, all the parts of "ſuch bodies will every moment be cloſely compreſſed, and "being rigid will re-act with equal force. Hence a quick and "powerful contraction and expanſion will ariſe in every part, "reſembling that ſwift kind of vibrations obſerved in ſtretched "ſtrings; how great theſe vibrations are may be learnt from "the inſtance of a bell, when ſtruck with a ſingle blow, by "which the whole bulk, however vaſt, will for a long time "expand, and contract itſelf in infinite ellipſes. And when "the attrition above deſcribed is produced, with what force and "velocity are all the particles of the rubbed body compreſſed,

" ſhaken, and looſened to their very intimate ſubſtance*?" And in proportion to the ſwiftneſs of this vibration, and the violence of the attrition and friction, will be the heat that is produced.

A piece of iron that would ſuſtain the preſſure of any weight, however large, without being warmed, may be made quite hot by the blow of a hammer; and even ſoft and un-elaſtic bodies may be warmed by percuſſion, provided the velocity with which their parts are made to give way to the blow is ſufficiently rapid. If a leaden bullet is laid upon an anvil, or any other hard body, and in that ſituation it is ſtruck with a ſmart blow of a hammer, it will be found to be much heated; but the ſame bullet in the ſame ſituation may be much more flattened by preſſure, or by the ſtroke of a very heavy body moving with a ſmall velocity, without being ſenſibly warmed.

To generate heat therefore the action of the powder upon the inſide of the piece muſt not only be ſufficient to ſtrain the metal, and produce a motion in its parts, but this effect muſt be extremely rapid; and the heat will be much augmented, if the exertion of the force and the duration of its action are momentaneous; for in that caſe, the fibres of the metal (if I may uſe the expreſſion) that are violently ſtretched, will return with their full force and velocity, and the ſwift vibratory motion and attrition before deſcribed will be produced.

The heat generated in a piece by firing is therefore as the force by which the particles of the metal are ſtrained and compreſſed, the ſuddenneſs with which this force is exerted, and the ſhortneſs of the time of its action; that is to ſay, as the ſtrength of the powder and the quantity of the charge, the quickneſs of its inflammation, and the velocity with which the generated fluid makes its eſcape.

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* Vide SHAW's tranſlation of BOERHAAVE's Chemiſtry, vol. I. p. 249.

Now the effort of any given charge of powder upon the gun is very nearly the ſame, whether it be fired with a bullet or without; but the velocity with which the generated elaſtic fluid makes its eſcape, is much greater when the powder is fired alone, than when it is made to impel one or more bullets; the heat ought therefore to be greater in the former caſe than in the latter, as I found by experiment.

But to make this matter ſtill plainer, we will ſuppoſe any given quantity of powder to be confined in a ſpace that is juſt capable of containing it, and that in this ſituation it is by any means ſet on fire. Let us ſuppoſe this ſpace to be the chamber of a piece of ordnance of any kind, and that a bullet, or any other ſolid body, is ſo firmly fixed in the bore immediately upon the charge, that the whole effort of the powder ſhall not be able to remove it. As the powder goes on to be inflamed, and the elaſtic fluid is generated, the preſſure upon the inſide of the chamber will be increaſed, till at length all the powder being burnt, the ſtrain upon the metal will be at its greateſt height, and in this ſituation things will remain, the coheſion or elaſticity of the particles of metal counterbalancing the preſſure of the fluid.

Under theſe circumſtances very little heat would be generated; for the continued effort of the elaſtic fluid would approach to the nature of the preſſure of a weight; and that concuſſion, vibration, and friction, among the particles of the metal, which in the colliſion of elaſtic bodies is the cauſe of the heat that is produced, would ſcarcely take effect.

But inſtead of being firmly fixed in its place, let the bullet now be moveable, but let it give way with great difficulty, and by ſlow degrees. In this caſe, the elaſtic fluid will be generated as before, and will exert its whole force upon the chamber of the piece; but as the bullet gives way to the preſſure, and moves on in the bore, the fluid will expand itſelf and grow weaker, and the particles of the metal will gradually return to their former ſituations; but the velocity with which the metal reſtores itſelf being but ſmall, the vibration that remains in the metal, after the elaſtic fluid has made its eſcape, will be very languid, as will be the heat that is generated by it.

But if, inſtead of giving way with ſo much difficulty, the bullet is much lighter, ſo as to afford but little reſiſtance to the elaſtic fluid in making its eſcape, or if the powder is fired without any bullet at all; then, there being little or nothing to oppoſe the flame in its paſſage through the bore, it will expand itſelf with an amazing velocity, and its action upon the gun will ceaſe almoſt in an inſtant, the ſtrained metal will reſtore itſelf with a very rapid motion, and a ſharp vibration will enſue, by which the piece will be much heated.

Of the effect of ramming the powder in the chamber of the piece.

The charge, conſiſting of 218 grains of powder, being put gently into the bore of the piece in a cartridge of very fine paper, without being rammed, the velocity of the bullets at a mean of the 40th, 41ſt, 42d, and 47th experiments, was at the rate of 1225 feet in a ſecond; but in the 68th, 69th, and 70th experiments, when the ſame quantity of powder was rammed down with five or ſix hard ſtrokes of the ram-rod, the mean velocity was 1329 feet in a ſecond. Now the total force or preſſure exerted by the charge upon the bullet is as the ſquare of its velocity, and $\overline{1329}^2$ is to $\overline{1225}^2$ as 1,1776 is to 1; or nearly as 6 is to 5; and in that proportion was the force of the given charge of powder increaſed by being rammed.

In the 71ſt experiment the powder was alſo rammed, but the vent, inſtead of being at the bottom of the bore, was at 1,3, and the velocity of the bullet was very conſiderably diminiſhed, being only at the rate of 1080 feet in a ſecond, inſtead of 1276 feet in a ſecond, which was the mean velocity with this charge, and with the vent in this ſituation when the powder was rammed. See the experiments N° 43, 44, 45, and 46.

When, inſtead of ramming the powder, or preſſing it gently together in the bore, it is put into a ſpace larger than it is capable of filling, the force of the charge is thereby very ſenſibly leſſened, as Mr. ROBINS and others have found by repeated trials. In my 30th experiment the charge, conſiſting of no more than 165 grains of powder, was made to occupy 3,2 inches of the bore inſtead of 1,45 inches, which ſpace it juſt filled when it was gently puſhed into its place without being rammed; the conſequence was, the velocity of the bullet, inſtead of being 1100 feet in a ſecond or upwards, was only at the rate of 914 feet in a ſecond, and the recoil was leſſened in proportion.

And from hence we may draw this practical inference, that the powder, with which a piece of ordnance or a fire-arm is charged, ought always to be preſſed together in the bore; and if it is rammed to a certain degree, the velocity of the bullet will be ſtill farther increaſed. It is well known, that the recoil of a muſket is greater when its charge is rammed than when it is not; and there cannot be a ſtronger proof that ramming increaſes the force of the powder.

Of the relation of the velocities of bullets to the charges of powder by which they are impelled.

It appears by all the experiments that have hitherto been made upon the initial velocities of bullets, that when the weights and dimenſions of the bullets are the ſame, and they are diſcharged from the ſame piece by different quantities of powder, the velocities are in the ſub-duplicate ratio of the weights of the charges very nearly.

The following table will ſhew how accurately this law obtained in the foregoing experiments.

	Velocities			
Charges.	Computed.	Actual.	Difference.	N° of exp.
437½	1764	1764	——	3
330	1533	1594	+ 61	2
310	1486	1459	− 27	1
290	1436	1436	0	7
218	1232	1225	− 7	4
208	1216	1256	+ 40	3
165	1083	1087	+ 4	2
145	1018	1040	+ 22	2
104	860	757	− 103	2

The computed velocities, as they are ſet down in this table, were determined from the ratio of the ſquare root of 437½ (the weight in grains of the largeſt charge of powder) to the mean velocity of the bullet with that charge and the vent at 0; *viz.* 1764 feet in a ſecond, and the ſquare root of the other charges expreſſed in grains. And the *actual* velocities are means of all experiments that were made under ſimilar circumſtances.

The fourth column ſhews the difference of the computed and actual velocities, or the number of feet in a ſecond by which the actual velocity exceeds or falls ſhort of the computed: and in the fifth column is ſet down the number of experiments with each charge, from the mean of which the actual velocity was determined.

The agreement of the computed and actual velocities will appear more ſtriking, if we take the ſum and difference of thoſe velocities with all the charges except the firſt: thus,

Sum of the velocities, — 1764.			
Computed.	Actual.	Difference.	N° of exp.
9864	9854	— 10	23

So that it appears, that the difference, or the actual velocity, was ſmaller than the computed by $\frac{1}{985}$ part only at a mean of 23 experiments.

But as by far the greater number of the experiments were made with the following charges, *viz.* 290, 218, 208, 165, and 145 grains of powder, let us take the ſum and difference of the computed and actual velocities of thoſe charges: thus,

Sum of the velocities			
Computed.	Actual.	Difference.	N° of exp.
5985	6044	+ 59	18

Here the agreement of the theory with the experiments is ſo very remarkable, that we muſt ſuppoſe it was in ſome meaſure accidental; for the difference of the velocities in repeating the ſame experiment is in general much greater than the difference of the computed and actual velocities in this inſtance; but, I think, we may fairly conclude, from the reſult of all theſe trials, that the velocities of like *muſket* bullets, when they are diſcharged from the ſame piece by different quantities of the ſame kind of powder, are very nearly in the ſub-duplicate ratio of the weights of the charges. Whether this law will hold good when applied to cannon balls, and bomb-ſhells of large dimenſions, I dare not at preſent take upon me to decide; but, for ſeveral reaſons that might be mentioned, I am rather of opinion, that it will not; at leaſt not with that degree of accuracy which obtained in theſe experiments.

Of the effect of placing the vent in different parts of the charge.

There have been two opinions with reſpect to the manner in which gun-powder takes fire. Mr. ROBINS ſuppoſes that the progreſs of its inflammation is ſo extremely rapid, "that all "the powder of the charge is fired and converted into an elaſtic "fluid, before the bullet is ſenſibly moved from its place;" while others have been of opinion, that the progreſs of the inflammation is much ſlower, and that the charge is ſeldom or never completely inflamed before the bullet is out of the gun.

The large quantities of powder that are frequently blown out of fire arms un-inflamed, ſeem to favour the opinion of the advocates for the gradual firing; but Mr. ROBINS endeavours to account for that circumſtance upon different principles, and ſupports his opinion by ſhewing that every increaſe of the charge within the limits of practice produces a proportional increaſe of the velocity of the bullet, and that when the powder is confined by a great additional weight, by firing two or more bullets at a time inſtead of one, the velocity is not ſenſibly greater than it ought to be according to his theory.

If this were a queſtion merely ſpeculative, it might not be worth while to ſpend much time in the diſcuſſion of it; but as it is a matter upon the knowledge of which depends the determination of many important points reſpecting artillery, and from which many uſeful improvements may be derived, too much pains cannot be taken to come at the truth. Till the manner in which powder takes fire, and the velocity with which the inflammation is propagated, are known, nothing can with certainty be determined with reſpect to the beſt form for the chambers of pieces of ordnance, or the moſt advantageous ſituation for the vent; nor can the force of powder, or the ſtrength that is required in different parts of the gun, be aſcertained with any degree of preciſion.

As it would be eaſy to determine the beſt ſituation for the vent from the velocity of the inflammation of powder being known, ſo on the other hand I had hopes of being able to come at that velocity by determining the effect of placing the vent in different parts of the charge; for which purpoſe the following experiments were made.

A table of experiments, ſhewing the effect of placing the vent in different parts of the charge.

Weight of the charge of powder.	Space occupied by the powder.	Vent from the bottom of the bore.	Velocity of the bullet at a medium.	Recoil meaſured upon the ribbon at a medium.	Number of experiments.
Grains.	Inches.	Inches.	Ft. in a ſec.	Inches.	
165	1,45	0	1087	14,465	2
. . .	. . .	1,32	1082	14,31	3
218	1,9	0	1225	17,93	4
. . .	. . .	1,3	1276	18,34	4
290	2,6	0	1427	22,626	3
. . .	. . .	1,3	1493	23,34	3
. . .	. . .	2,6	1460	23,286	4
. . .	. . .	0	1444	23,135	4
. . .	. . .	2,6	1413	24,5	3
310	2,7	0	——	24,69	1
. . .	. . .	1,32	——	24,95	1
. . .	. . .	2,65	——	24,9	1
330	2,9	0	1594	26,075	2
. . .	. . .	1,3	1625	26,4	2
. . .	. . .	2,6	1525	25,3	2
437½	3,9	0	1764	33,3	3
. . .	. . .	2,6	1751	32,866	3

By the foregoing experiments it appears, firſt, that the difference in the force of any given charge of powder which ariſes from the particular ſituation of the vent is extremely ſmall.

With 165 grains of powder, and the vent at 0, the velocity of the bullet at a mean of two experiments (*viz.* the 20th and 21ſt) was 1087 feet in a ſecond; and with the ſame charge, and the vent at 1,32 inches, the velocity at a mean of the 22d, 23d, and 24th experiments, was 1082 feet in a ſecond;

the difference, equal five feet in a ſecond, is leſs than what occurred in a repetition of the ſame experiment.

With 218 grains of powder, and the vent at 0, the velocity at a mean in the 40th, 41ſt, 42d, and 47th experiments, was at the rate of 1225 feet in a ſecond; and with the ſame charge, and the vent at 1,3, the velocity was 1276 feet in a ſecond at a mean of four experiments, *viz.* the 43d, 44th, 45th, and 46th.

In the firſt ſet of experiments, with 290 grains of powder, the velocities were,

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
	1414	1476	1502
	1455	1520	1450
	1412	1483	1433
			1454
	3)4281	3)4479	4)5839
Means	1427	1493	1460

See the experiments from N° 48. to N° 57. incluſive.

In the ſecond ſet the velocities were,

	Vent at 0.	Vent at 2,6.
	1419	1438
	1460	1423
	1462	1378
	1436	
	4)5777	3)4239
Means	1444	1413

See the experiments from N° 109. to N° 115. incluſive.

And taking the means of all the velocities in both ſets in each poſition of the vent it will be,

	Vent at 0.	Vent at 1.3.	Vent at 2,6.
Mean velocity	1436	1493	1437

The mean recoils in theſe experiments were,

Vent at 0.	Vent at 1,3.	Vent at 2,6.
22,88	23,34	23,61

In the experiments with 310 grains of powder the velocities of the bullets were not determined with ſufficient accuracy to be depended on; but the recoils, which were meaſured with great nicety, were as follows, *viz.*

Vent at 0.	Vent at 1,3.	Vent at 2,6
24,69	24,95	24,9

With 330 grains of powder the mean velocities and recoils were,

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
Velocities	1594	1625	1525
Recoils	26,075	26,4	25,3

In the experiments with 437½ grains (an ounce avoirdupois) of powder the velocities and recoils were,

	Vent at 0.		Vent at 2,6.	
	Velocity.	Recoil.	Velocity.	Recoil.
	1738	33,	1707	32,5
	1824	33,3	1757	33,2
	1728	33,6	1789	32,9
	3)5291	3)99,9	3)5253	3)98,6
Means	1764	33,3	1751	32,866

Secondly, From the reſult of all theſe experiments it appears, that the effect of placing the vent in different poſitions with reſpect to the bottom of the chamber is different, in different charges; thus, with 165 grains of powder the velocity of the bullet was rather diminiſhed by removing the vent from 0, or the bottom of the bore to 1,32; but with 218 grains of powder the velocity was a little increaſed, as was alſo the recoil. With 290 grains of powder the velocity was greateſt when the powder was lighted at the vent 1,3 which was near the middle of the charge, and rather greater when it was lighted at the top, or immediately behind the bullet, than when it was lighted at the bottom. And by the recoil it would ſeem, that the velocities of the bullets varied nearly in the ſame manner when the charge conſiſted of 310 grains of powder.

With 330 grains of powder, both the velocity and the recoil were greater when the powder was lighted at the middle of the charge, than when it was lighted at the bottom; but they were leaſt of all when it was lighted near the top. And when *an ounce* of powder was made uſe of for the charge, its force was greateſt when it was lighted at the bottom. But the difference in the force exerted by the powder which aroſe from the particular poſition of the vent was in all caſes ſo inconſiderable (being, as I have before obſerved, leſs than what frequently occurred in repeating the ſame experiment) that no concluſion can be drawn from the experiments, except only this, that any given charge of powder exerts nearly the ſame force, whatever is the poſition of the vent.

And hence the following practical inference naturally occurs, *viz.* that in the formation of fire-arms no regard need be had to any ſuppoſed advantages that gun-ſmiths and others have hitherto imagined were to be derived from particular ſituations for

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the vent, ſuch as diminiſhing the recoil, increaſing the force of the charge, &c.; but the vent may be indifferently in any part of the chamber where it will beſt anſwer upon other accounts: and there is little doubt but the ſame thing will hold good in great guns, and all kinds of heavy artillery.

Almoſt every workman who is at all curious in fire-arms has a particular fancy with regard to the beſt form for the bottom of the chamber, and the proper poſition of the vent. They in general agree, that the vent ſhould be as low or far back as poſſible, in order, as they pretend, to leſſen the recoil; but no two of them make it exactly in the ſame manner. Some make the bottom of the chamber flat, and bring the vent out even with the end of the breech-pin. Others make the vent ſlanting through the breech-pin, in ſuch a manner as to enter the bore juſt in its axis. Others again make the bottom of the chamber conical; and there are thoſe who make a little cylindric cavity in the breech-pin, of about two-tenths of an inch in diameter, and near half an inch in length, coinciding with the axis of the bore, and bring out the vent even with the bottom of this little cavity.

The objection to the firſt method is, the vent is apt to be ſtopped up by the foul matter that adheres to the piece after firing, and which is apt to accumulate, eſpecially in damp weather. The ſame inconvenience in a ſtill greater degree attends the other methods, with the addition of another, ariſing from the increaſed length of the vent; for the vent being longer it is not only more liable to be obſtructed, but it takes a longer time for the flame to paſs through it into the chamber, in conſequence of which the piece is ſlower in going off, or, as ſportſmen term it, is apt to hang fire.

The form I would recommend for the bottom of the bore is that of a hemiſphere; and the vent ſhould be brought out directly through the ſide of the barrel, in a line perpendicular to its axis, and pointing to the center of the hemiſpheric concavity of the chamber.

In this caſe the vent would be the ſhorteſt poſſible; it would be the leaſt liable to be obſtructed, and the piece would be more eaſily cleaned, than if the bottom of the bore was of any other form. All theſe advantages, and ſeveral others not leſs important, would be gained by making the bottom of the bore and vent of great guns in the ſame manner.

A new method of determining the velocities of bullets.

From the equality of *action* and *re-action* it appears, that the *momentum* of a gun muſt be preciſely equal to the momentum of its charge; or that the weight of the gun, multiplied into the velocity of its recoil, is juſt equal to the weight of the bullet and of the powder (or the elaſtic fluid that is generated from it) multiplied into their reſpective velocities: for every particle of matter, whether ſolid or fluid, that iſſues out of the mouth of a piece, muſt be impelled by the action of ſome power, which power muſt *re-act* with equal force againſt the bottom of the bore.

Even the fine inviſible elaſtic fluid that is generated from the powder in its inflammation cannot put itſelf in motion without re-acting againſt the gun at the ſame time. Thus we ſee pieces, when they are fired with powder alone, recoil as well as when their charges are made to impel a weight of ſhot, though the recoil is not in the ſame degree in both caſes.

It is eaſy to determine the velocity of the recoil in any given caſe, by ſuſpending the gun in an horizontal poſition by two pendulous rods, and meaſuring the arc of its aſcent, by means of a ribbon according to the method already deſcribed, and this will give the momentum of the gun, its weight being known, and conſequently the momentum of its charge. But in order to determine the velocity of the bullet from the recoil, it will be neceſſary to find out how much the weight and velocity of the elaſtic fluid contributes to it.

That part of the recoil which ariſes from the expanſion of this fluid is always very nearly the ſame, whether the powder is fired alone, or whether the charge is made to impel one or more bullets, as I have found by a great variety of experiments.

If therefore a gun, ſuſpended according to the method preſcribed, is fired with any given charge of powder, but without any bullet or wad, and the recoil is obſerved, and if the ſame piece is afterwards fired with the ſame quantity of powder, and a bullet of a known weight, the exceſs of the velocity of the recoil in the latter caſe, over that in the former, will be proportional to the velocity of the bullet; for the difference of theſe velocities, multiplied into the weight of the gun, will be equal to the weight of the bullet multiplied into its velocity.

Thus if W is put equal to the weight of the gun,
U = the velocity of its recoil, when it is fired with any given charge of powder, without any bullet,
V = the velocity of the recoil, when the ſame charge is made to impel a bullet,
B = the weight of the bullet, and
v = its velocity,

It will be $v = \frac{\overline{V-U} \times W}{B}$.

Let us ſee how this method of determining the velocities of bullets will anſwer in practice.

In the 94th experiment the recoil, with 165 grains of powder, without a bullet, was 5,5 inches, and in the 95th experiment, with the ſame charge, the recoil was 5,6 inches. The mean is 5,55 inches; and the length of the rods by which the barrel was ſuſpended being 64 inches, the velocity of the recoil (= U) anſwering to 5,55 inches meaſured upon the ribbon, is that of 1,1358 feet in a ſecond.

In five experiments, with the ſame charge of powder, and a bullet weighing 580 grains, the recoil was as follows, *viz.*

The 20th experiment		14,73 inches
21ſt	-	14,2
22d	-	14,8
23d	-	14,58
24th	-	14,68

5)73, (= 14,6 inches at a mean.

And the velocity of the recoil (= V) anſwering to the length is that of 2,9880 feet in a ſecond: conſequently V − U, or 2,9880 − 1,1358 is equal to 1,8522 feet in a ſecond.

But as the velocities of recoil are known to be as the chords of the arcs through which the barrel aſcends, it is not neceſſary in order to determine the velocity of the bullet to compute the velocities V and U; but the quantity $\overline{V-U}$, or the difference of the velocities of the recoil when the given charge is fired with and without a bullet, may be computed from the value of the difference of the chords, by one operation. Thus the velocity anſwering to the chord 9,05 is that of 1,8522 feet in a ſecond, which is juſt equal to $\overline{V-U}$, as was before found.

The weight of the barrel, together with its carriage, was $47\frac{1}{4}$ pounds, to which three quarters of a pound is to be added on account of the weight of the rods by which it was ſuſpended, which makes $W = 48$ pounds, or 336,000 grains, and the weight of the bullet was 580 grains. B is therefore to W as 580 is to 336,000, that is, as 1 is to 579,31 very nearly; and v ($= \frac{\overline{V-U}\times W}{B}$ is equal to $\overline{V-U}\times 579{,}31$.

The value of $\overline{V-U}$ anſwering to the experiments before mentioned was found to be 1,8522; conſequently the velocity of the bullets ($= v$) was $1{,}8522 \times 579{,}31 = 1073$ feet in a ſecond, which is extremely near 1083 feet in a ſecond, the mean of the velocities, as they were determined by the pendulum.

But the computation for determining the velocity of a bullet upon theſe principles may be rendered ſtill more ſimple and eaſy in practice; for the velocities of the recoil being as the chords meaſured upon the ribbon, if

c is put equal to the chord of the recoil expreſſed in Engliſh inches, when the piece is fired with powder only, and

$C =$ the chord when a bullet is diſcharged by the ſame charge,

then $C - c$ will be as $V - U$; and conſequently as $\frac{\overline{V-U}\times W}{B}$, which meaſures the velocity of the bullet, the ratio of W to B remaining the ſame.

If therefore we ſuppoſe a caſe in which $C - c$ is equal to one inch, and the velocity of the bullet is computed from that chord, the velocity in any other caſe, wherein $C - c$ is greater or leſs than one inch, will be found by multiplying the difference of the chords C and c by the velocity that anſwers to a difference of one inch.

The length of the parallel rods by which the barrel was ſuſpended being 64 inches, the velocity of the recoil anſwering to $C - c = 1$ inch meaſured upon the ribbon is 0,204655 parts of a foot in a ſecond; and this is alſo, in this caſe the value of $V - U$; the velocity of the bullet is therefore $v = 0,204655 \times 579,31 = 118,35$ feet in a ſecond.

Conſequently the velocity of the bullet expreſſed in feet *per* ſecond may in all caſes be found by multiplying the difference of the chords C, and *c*, by 118,35, the weight of the barrel, the length of the rods by which it is ſuſpended, and the weight of the bullet remaining the ſame, and this whatever the charge of powder may be that is made uſe of, and however it may differ in ſtrength or goodneſs.

According to this rule the velocities of the bullets in the following experiments have been computed from the recoil; and by comparing them with the velocities ſhewn by the pendulum, we ſhall be enabled to judge of the accuracy of this new method of determining the velocities of bullets.

In the 76th and 77th experiments, when the piece was fired with 145 grains of powder and a bullet, the recoil was 13,25 and 13,15, or 13,2 at a mean; and with the ſame charge of powder, without a bullet, the recoil was 4,5 and 4,3, or 4,4 at a mean (ſee the 84th and 93d experiments). $C - c$ is therefore $13,2 - 4,4 = 8,8$ inches, and the velocity of the bullets $= 8,8 \times 118,35 = 1045$ feet in a ſecond. The mean of the velocities as they were determined by the pendulum is that of 1040 feet in a ſecond. In the 104th and 105th experiments the recoil was 12,92 and 13,28, and the velocity computed from the mean of thoſe chords is 1030 feet in a ſecond; but the velocity ſhewn by the pendulum was no more than about 900 feet in a ſecond. As the recoil was ſo nearly equal to what it was in the 76th and 77th experiments before mentiond, when the velocities ſhewn by the recoil and by the pendulum were almoſt exactly the ſame, I am inclined to believe, that there muſt have been ſome miſtake in determining the velocities by the pendulum in theſe laſt experiments, and that the velocity ſhewn by the recoil is moſt to be depended on.

With 290 grains, or half the weight of the bullet in powder, in the 48th, 49th, and 50th experiments, the recoil was 22,58, 22,92, and 22,38; and the recoil, with the ſame charge of powder, without a bullet, at a mean of the 60th and 99th experiments, was 10,66. The mean of the velocities of the bullets, computed from the recoil, is therefore 1416 feet in a ſecond, and the velocity ſhewn by the pendulum was 1427 feet in a ſecond: the difference is not conſiderable. The mean of the velocities in the 109th, 110th, 111th, and 112th experiments is by the recoil 1464, and by the pendulum 1444 feet in a ſecond.

With 330 grains of powder the velocities of the bullets appear to have been as follows, *viz.*

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
By the recoil	1543	1620	1610
By the pendulum	1594	1625	1528

See the 62d, 63d, 64th, 65th, 66th, 67th, and 17th experiments.

The uniformity of the recoil was in all caſes very remarkable. Thus, in the firſt ſet of experiments with 290 grains of powder (from the 48th to the 57th experiment incluſive), the recoil was,

	Vent at 0.	Vent at 1,3.		Vent at 2,6.
	22,58	23,21		23,06
	22,92	23,76		23,26
	22,38	23,06		23,26
				23,56
	3)67,88	3)70,03		4)93,14
Means =	22,626	23,343	and	23,285

If now we take a mean of the 60th and 99th experiments, and call the recoil, without a bullet, 10,66 as before, the velocities will turn out,

	Vent at 0.	Vent at 1,3.	Vent at 2,6.
By the recoil - -	1416	1501	1494
And by the pendulum they were	1427	1493	1494
The difference is only .	− 11	+ 8	+34

The recoil was equally regular in the 117th and five ſucceeding experiments, when the charge was no leſs than 437½ grs. = 1 ounce avoirdupois in powder; and the velocities of the bullets determined from the recoil are very nearly the ſame as they were ſhewn by the pendulum. Thus, in the 117th, 118th, and 119th experiments the mean recoil was 33,3; and in the 120th, 121ſt and 122d experiments it was 32,866. And if the recoil without a bullet is called 17,9, as it was determined by the 123d experiment, which was made immediately after the experiments before mentioned, then will the velocities be,

	Vent at 0.	Vent at 2,6
By the recoil - -	1822	1771
And by the pendulum they were	1764	1751

The difference is only - +58 and +20 feet in a ſecond, which is leſs than what frequently occurs in repeating the ſame experiment.

In the 11th, 12th, 13th, and 14th experiments, when the piece was fired with 310 grains of powder and a bullet, the recoil was 24,69, 24,95, 24,9, and 24,9: and in the 15th, 16th, 18th, and 19th experimentss with 330 grains of powder, the recoil was 26,2, 26,2, 26,3, and 26,4. The regularity of theſe numbers is very ſtriking; and though we cannot compare the velocities of the bullets determined by the two methods as we have done in other caſes (as there are reaſons to believe, that the velocities, as they are ſet down in the tables, are not much to be depended on, and as the recoil, with the given charge of 310 grains of powder without a bullet, is not known) yet the regularity of the recoil in theſe experiments affords good grounds to conclude, that the method of determining the velocities of bullets founded upon it muſt be very accurate.

But of all the experiments thoſe numbered from 84 to 92 incluſive afford the ſtrongeſt proof of the accuracy of this method. In thoſe every poſſible precaution was taken to prevent errors ariſing from adventitious circumſtances, and the weights of the bullets and their velocities were ſo various, that the uniform agreement of the two methods of determining the velocities in thoſe trials amounts almoſt to a demonſtration of the truth of the principles upon which this new method is founded.

By the following table the reſult of theſe experiments may be ſeen at one view.

The experiments.	Weight of the bullets.	The barrel heavier than the bullet.	The recoil.	Velocity of the bullet.		Difference.
				By the recoil.	By the pendulum.	
	Grs.	$\frac{W}{B}=$	$C=$	$v=$	$v=$	
84th and 93d	—	—	$c=$ 4,4	—	—	—
85th	90	3733,3	7,16	2109	1763	+ 346
86th	251	1338,6	9,62	1430	1317	+ 113
87th	354	949,15	11,03	1288	1136	+ 152
88th	600	560,	15,22	1240	1229	+ 11
89th	603	557,22	15,13	1224	1229	+ 5
90th	1184	283,78	21,92	1017	978	− 39
91ſt	1754	191,56	27,18	893	916	− 23
92d	2352	141,86	32,25	812	833	− 21

The charge of powder conſiſted of 145 grains in weight in each experiment.

In order to ſhew, in a more ſtriking manner, the reſult of theſe experiments, and the compariſon of the two methods of aſcertaining the velocities of bullets, I have drawn the fig. 16. where the numbers that are marked upon the line AB are taken from A towards B, in proportion to the weights of the bullets; while the lines drawn from thoſe numbers perpendicular from AB (as w, v, for inſtance, at the number 2352) and ending at the curve c, d, expreſs their velocities, as ſhewn by the pendulum. The continuation of thoſe lines on the oppoſite ſide of the line AB ſhew the recoil, and alſo the velocities of the bullets as determined from it; thus w, r, and the (dotted) lines parallel to it, which end at the line *g*, *f*, expreſs the recoil; and the portion of each of thoſe lines that is comprehended between the line AB and the curve *m*, *n* (as *w*, *u*) is as the velocity of the bullet in the ſeveral experiments. The line A, *e*, denotes the weight of the charge of powder; and the line A, *m*, the velocity with which the elaſtic fluid eſcapes out of the piece, when the powder is fired without any bullet.

Upon an inſpection of this figure, as well as from an examination of the foregoing table, it appears, that the velocities determined by the two methods agree with great nicety in all the experiments after the 87th; but in the 87th experiment, and alſo in the 86th, but particularly in the 85th, the difference in the reſult of theſe different methods is very conſiderable: and it is remarkable, that in thoſe experiments where they diſagree moſt, the velocities of the bullets, as determined by the pendulum, are extremely irregular; while, on the other hand, the gradual increaſe of the recoil as the bullets were heavier, and the great regularity of the correſponding velocities, afford good grounds to conclude, that this diſagreement is not owing to any inaccuracy in the new method of aſcertaining the velocities, but to ſome other cauſe that remains to be inveſtigated.

But before we proceed in this inquiry, let us ſeparate the five laſt experiments in the foregoing table; and, ſumming up the velocities determined by the two methods, we ſhall ſee by their difference how thoſe methods agreed upon the whole, in this inſtance.

Experiments.	Weight of the bullets.	Velocity. By the recoil.	Velocity. By the pendulum.	Difference.
	Grs.			
88th	600	1240	1229	+ 11
89th	603	1224	1229	− 5
90th	1184	1017	978	+ 39
91ſt	1754	893	916	− 23
92d	2352	812	833	− 21
Sums and diff. of the velocities		5186	5185	+ 1

Here the difference in the reſult of the two methods does not amount to $\frac{1}{5000}$th part of the whole velocity; but I lay no ſtreſs upon this extraordinary argument. I am ſenſible that it muſt in ſome degree have been accidental; but as the difference in the velocities, computed by theſe different methods, was in no inſtance conſiderable, not being in any caſe ſo great as what frequently occurred in the moſt careful repetition of the ſame experiment, and as the velocities, as determined by the recoil, were much more regular than thoſe ſhewn by the pendulum, as appears by comparing the curves *g*, *f*, and *m*, *n*, (fig. 16.) with the crooked line *c*, *d*, I think we may fairly conclude, that this new method may with ſafety be relied on in practice.

The greateſt difference in the velocities, as aſcertained by the two methods, appears, in the inſtance of the 85th experiment, where the velocity determined from the recoil exceeds that ſhewn by the pendulum by 346 feet in a ſecond, the former velocity being that of 2109 feet in a ſecond, the latter only 1763 feet in a ſecond; and in the two ſucceeding experiments, the velocities ſhewn by the pendulum are likewiſe deficient, though not in ſo great a degree.

This apparent deficiency remains now to be accounted for; and, firſt, it cannot be ſuppoſed, that it aroſe from any imperfection in Mr. ROBINS's method of determining the velocities of bullets; for that method is founded upon ſuch principles as leave no room to doubt of its accuracy; and the practical errors that occur in making the experiments, and which cannot be intirely prevented, or exactly compenſated, are in general ſo ſmall, that the difference of the velocities in queſtion cannot be attributed to them. It is true, the effect of thoſe errors is more likely to appear in experiments made under ſuch circumſtances as thoſe under which the experiments we are now ſpeaking of were made, than in any other caſe; for the bullets being very light, the arc of the aſcent of the pendulum was but ſmall, and a ſmall miſtake in meaſuring the chord upon the ribbon would have produced a very conſiderable error in computing the velocity of the bullet: thus, a difference of one tenth of an inch, more or leſs, upon the ribbon in the 85th experiment, would have made a difference in the velocity of more than 120 feet in a ſecond. But independent of the pains that were taken to prevent miſtakes, the ſtriking agreement of the velocities determined by the two methods in the experiments which immediately follow, as alſo in all other caſes where they could be compared, affords abundant reaſon to conclude, that the errors ariſing from thoſe cauſes were in no inſtance very conſiderable.

But if both methods of aſcertaining the velocities of bullets are to be relied on, then the difference of the velocities, as determined by them in theſe experiments, can only be accounted for by ſuppoſing that it aroſe from their having been diminiſhed by the reſiſtance of the air in the paſſage of the bullets from the mouth of the piece to the pendulum; and this ſuſpicion will be much ſtrengthened when we conſider how great the reſiſtance is that the air oppoſes to bodies that move very ſwiftly in it, and that the bullets in theſe experiments were not only projected with great velocities, but were alſo very light, and conſequently more liable to be retarded by the reſiſtance on that account.

To put the matter beyond all doubt, let us ſee what the reſiſtance was that theſe bullets met with, and how much their velocities were diminiſhed by it. The weight of the bullet (in the 85th experiment) was 90 grains; its diameter was 0,78 of an inch, and it was projected with a velocity of 2109 feet in a ſecond.

If now a computation be made according to the method laid down by Sir ISAAC NEWTON for compreſſed fluids, it will be found, that the reſiſtance to this bullet was not leſs than $8\frac{1}{2}$ lbs. avoirdupois, which is ſomething more than 660 times its weight. But Mr. ROBINS has ſhewn, by experiment, that the reſiſtance of the air to bodies moving in it with very great velocity is near three times greater than Sir ISAAC has determined it, and as the velocity with which this bullet was impelled is conſiderably greater than any in Mr. ROBINS's experiments, it is highly probable, that the reſiſtance in this inſtance was at leaſt 2000 times greater than the weight of the bullet.

The diſtance from the mouth of the piece to the pendulum, as we have before obſerved, was 12 feet; but, as there is reaſon to think, that the blaſt of the powder, which always follows the bullet, continues to act upon it for ſome ſenſible ſpace of time after it is out of the bore, and by urging it on counter-balances, or at leaſt counter-acts in a great meaſure the reſiſtance of the air, we will ſuppoſe, that the reſiſtance does not begin, or rather that the motion of the bullet does not begin to be retarded, till it has got to the diſtance of two feet from the muzzle. The diſtance, therefore, between the barrel and the pendulum, inſtead of 12 feet, is to be eſtimated at 10 feet; and as the bullet took up about $\frac{1}{192}$ part of a ſecond in running over that ſpace, it muſt in that time have loſt a velocity of about 335 feet in a ſecond, as will appear upon making the computation, and this will very exactly account for the apparent diminution of the velocity in the experiment; for the difference of the velocities, as determined by the recoil and by the pendulum, $= 2109 - 1763 = 346$ feet in a ſecond, is extremely near 335 feet in a ſecond, the diminution of the velocity by the reſiſtance as here determined.

If the diminution of the velocities of the bullets in the two ſubſequent experiments be computed in like manner, it will turn out in the 86th experiment $= 65$ feet in a ſecond, and in the 87th experiment $= 33$ feet in a ſecond; and making theſe corrections, the compariſon of the two methods of aſcertaining the velocities will ſtand thus:

	85th exp.	86th exp.	87th exp.
Velocities ſhewn by the pendulum,	1763	1317	1136
Add the diminution of the velocity by the reſiſtance of the air,	335	65	33
	2098	1382	1169
Velocity by the recoil,	2109	1430	1288
The difference =	+11	+48	+119

So that it appears, notwithſtanding theſe corrections, that the velocities in the 86th and 87th experiments, and particularly in the laſt, as they were determined by the pendulum, are ſtill conſiderably deficient. But the manifeſt irregularity of the velocities in thoſe inſtances affords abundant reaſon to conclude, that it muſt have ariſen from ſome extraordinary accidental cauſe, and therefore, that little dependance is to be put upon the reſult of thoſe experiments. I cannot take upon me to determine poſitively what the cauſe was which produced this irregularity; but I ſtrongly ſuſpect, that it aroſe from the breaking of the bullets in the barrel by the force of the exploſion: for theſe bullets, as has already been mentioned, were formed of lead, incloſing leſſer bullets of plaſter of Paris; and I well remember to have obſerved at the time ſeveral ſmall fragments of the plaſter which had fallen down by the ſide of the pendulum. I confeſs, I did not then pay much attention to this circumſtance, as I naturally concluded, that it aroſe from the breaking of the bullet in penetrating the target of the pendulum, and that the ſmall pieces of plaſter I ſaw upon the ground had fallen out of the hole by which the bullet entered. But if the bullets were not abſolutely broken in pieces in firing, yet, if they were conſiderably bruiſed, and the plaſter or a part of it were ſeparated from the lead, ſuch a change in their form might produce a great increaſe of the reſiſtance, and even their initial velocities might be affected by it, for their form being changed from that of a globe to ſome other figure, they might not fit the bore, and a part of the force of the charge might be loſt by the windage.

That this actually happened in the 87th experiment ſeems very probable, as the velocity with which the bullet was projected, as it was determined by the recoil, is conſiderably leſs in proportion in that experiment than in either of thoſe that precede it in that ſet, or in thoſe which follow it, as will appear upon inſpecting the curvature of the line *m*, *n*, fig. 16. But I forbear to inſiſt further upon this matter.

As I have made an allowance for the reſiſtance of the air in theſe experiments, it may be expected that I ſhould do it in all other caſes; but, I think, it will appear upon enquiry, that the diminution of the velocities of the bullets on that account was in general ſo inconſiderable that it might ſafely be neglected: thus, for inſtance, in the experiments with an ounce of powder, when the velocity of the bullet was more than 1750 feet in a ſecond, the diminution turns out no more than about 25 or 30 feet in a ſecond, though we ſuppoſe the full reſiſtance to have begun ſo near as two feet from the mouth of the piece; and in all caſes where the velocities were leſs, the effect of the reſiſtance was leſs in a much greater proportion: and even in this inſtance there is reaſon to think, that the diminution of the velocity as we have determined it is too great; for the flame of gun-powder expands with ſuch an amazing rapidity, that it is ſcarcely to be ſuppoſed but that it follows the bullet, and continues to act upon it more than two feet, or even four feet, from the gun, and when the velocity of the bullet is leſs, its action upon it muſt be ſenſible at a ſtill greater diſtance.

With 218 grains of powder the recoil appears to have been very uniform; but if the velocities of the bullets are determined from the recoil in the 40th and ſeven following experiments, when this charge was made uſe of, and from the recoil without a bullet in the 72d and 73d experiments, the velocities will turn out conſiderably too ſmall, as we ſhall ſee by making the computation.

The

		Vent at 0.		Vent at 1,3.
The recoil in the	40th exp. was	18,	and in the 43d exp. it was	18,3
	41ſt	17,71	44th	18,35
	42d	17,91	45th	18,35
	47th	8,1	46th	18,35
		4)71,72		4)73,35
	Means =	17,93	and	18,34

And in the 72d and 73d experiments the recoil, with the ſame charge without a bullet, was 8,72, and 8,47 = 8,595 at a medium, the velocities therefore turn out,

	Vent at 0.		Vent at 1,3.	
By the recoil	1105	-	1153	
inſtead of	1225	and	1276	as they were ſhewn by the pend.

The difference 120 and 123 feet in a ſecond amounts to near one twelfth part of the whole velocity.

This difference is undoubtedly owing to the recoil without a bullet being taken too great; for it is not only greater than it ought to be, in order that the velocities of the bullets may come out right; but it is conſiderably greater in proportion than the recoil with any other charge.

Thus, with 145 grains of powder the recoil was 4,4
with 165 grains - - it was 5,55
290 grains - - - 10,66
330 grains - - - 12,7
and with 437½ grains - - - it was 17,9

And if the recoil with 218 grains is determined from theſe numbers by interpolation, it comes out 7,5; and with that

value

value for C the velocities of the bullets in the before mentioned experiments appear to be,

	Vent at 0.		Vent at 1,3.	
	1243	and	1283	by the recoil
which is extremely near	1225	and	1276	the velocities

ſhewn by the pendulum.

It is to be remembered, that the 72d and 73d experiments, from which we before determined the recoil with the given charge of powder without a bullet, were not made upon the ſame day with the experiments before mentioned; and it is well known, that the force of powder is different upon different days. And it is worthy of remark, that in thoſe two experiments the ſtrength of government powder appeared to be conſiderably the greateſt. I mention theſe circumſtances to ſhew the probability there is, that the recoil in thoſe experiments, from ſome unknown cauſe, was greater than it ought to have been, or rather than it would have been, had the experiments been made at the ſame time when the experiments with the bullets were made; or at any other time under the ſame circumſtances.

As this method of determining the velocities of the bullets did not occur to me till after I had finiſhed the courſe of my experiments, and had taken down my apparatus, I have not had an opportunity of aſcertaining the recoil, with and without a bullet, with that degree of preciſion that I could wiſh. If I had thought of it ſooner, or if I had recollected that paſſage in Mr. ROBINS's new Principles of Gunnery, where he ſays, "The part of the recoil, ariſing from the expanſion of "the powder alone, is found to be no greater when it impels "a leaden bullet before it, than when the ſame quantity is fired "without any wad to confine it:" I ſay, if that paſſage had occurred to me before it had been too late, I certainly ſhould have taken ſome pains to have aſcertained the fact; but as it is, I think, enough has been done to ſhew, that there is the greateſt probability that the velocities of bullets may in all caſes be determined by the recoil with great accuracy; and I hope ſoon to have it in my power to put the matter out of all doubt, and to verify this new method by a courſe of concluſive experiments which I am preparing for that purpoſe.

In the mean time I would juſt obſerve, that if this method ſhould be found to anſwer, when applied to muſket bullets, it cannot fail to anſwer equally well when it is applied to cannon balls and bomb ſhells of the largeſt dimenſions; and it is apprehended, that it will be much preferable to any method hitherto made public; not only as it may be applied indifferently to all kinds of military projectiles, and that with very little trouble or expence in making the experiment; but alſo becauſe by it the velocities with which bullets are *actually projected* are determined; whereas by the pendulum their velocities can only be aſcertained at ſome diſtance from the gun, and after they have loſt a part of their initial velocities by the reſiſtance of the air through which they are obliged to paſs to arrive at the pendulum.

At the trifling expence of ten or fifteen pounds an apparatus might be conſtructed that would anſwer for making the experiments with all the different kinds of ordnance in the Britiſh ſervice. The advantages that might be derived from ſuch a ſet of experiments are too obvious to require being mentioned.

Of a very accurate method of proving gun-powder.

All the *eprouvettes*, or powder-triers, in common uſe are defective in many reſpects. Neither the abſolute force of gunpowder can be determined by means of them, nor the comparative force of different kinds of it, but under circumſtances very different from thoſe in which the powder is made uſe of in ſervice.

As the force of powder ariſes from the action of an elaſtic fluid that is generated from it in its inflammation, the quicker the charge takes fire, the more of this fluid will be generated in any given ſhort ſpace of time, and the greater of courſe will be its effect upon the bullet. But in the common method of proving gun-powder, the weight by which the powder is confined is ſo great in proportion to the quantity of the charge, that there is time quite ſufficient for the charge to be all inflamed, even when the powder is of the ſloweſt compoſition, before the body to be put in motion can be ſenſibly removed from its place. The experiment, therefore, may ſhew which of two kinds of powder is the ſtrongeſt, when equal quantities of both are confined in equal ſpaces, and completely inflamed; but the degree of the inflammability, which is a property eſſential to the goodneſs of the powder, cannot by theſe means be aſcertained.

Hence it appears, how powder may anſwer to the proof, ſuch as is commonly required, and may nevertheleſs turn out very indifferent when it comes to be uſed in ſervice. And this, I believe, frequently happens; at leaſt I know complaints from officers of the badneſs of our powder are very common; and I would ſuppoſe that no powder is ever received by the

Board of Ordnance but ſuch as has gone through the eſtabliſhed examination, and has anſwered to the uſual teſt of its being of the ſtandard degree of ſtrength.

But though the common powder triers may ſhew powder to be better than it really is, they never can make it appear to be worſe than it is; it will therefore always be the intereſt of thoſe who manufacture that commodity to adhere to the old method of proving it. But the purchaſer will find his account in having it examined in a method by which its goodneſs may be aſcertained with greater preciſion.

The method I would recommend is as follows. A quantity of powder being provided, which, from any previous examination or trial, is known to be of a proper degree of ſtrength to ſerve as a ſtandard for the proof of other powder, a given charge of it is to be fired, with a fit bullet, in a barrel ſuſpended by two pendulous rods, according to the method before deſcribed, and the recoil is to be carefully meaſured upon the ribbon. And this experiment being repeated three or four times; or oftener if there is any difference in the recoil, the mean and the extremes of the chords may be marked upon the ribbon by black lines drawn acroſs it, and the word *proof* may be written upon the middle line; or if the recoil is uniform (which it will be to a ſufficient degree of accuracy, if care is taken to make the experiments under the ſame circumſtances) then the *proof mark* is to be made in that part of the ribbon to which it was conſtantly drawn out by the recoil in the different trials.

The recoil, with a known charge of ſtandard powder, being thus aſcertained and marked upon the ribbon, let an equal quantity of any other powder (that is to be proved) be fired in the ſame barrel, with a bullet of the ſame weight, and every other circumſtance alike, and if the ribbon is drawn out as far or farther than the proof mark, the powder is as good or better than the ſtandard; but if it falls ſhort of that diſtance, it is worſe than the ſtandard, and is to be rejected.

For the greater the velocity is with which the bullet is impelled, the greater will be the recoil; and when the recoil is the ſame, the velocities of the bullets are equal, and the powder is of the ſame degree of ſtrength, if the quantity of the charge is the ſame. And if care is taken in proportioning the charge to the weight of the bullet, to come as near as poſſible to the medium proportion that obtains in practice, the determination of the goodneſs of gun-powder from the reſult of this experiment cannot fail to hold good in actual ſervice.

Fig. 14. repreſents the propoſed apparatus, drawn to a ſcale of one foot to the inch. *a*, *b*, is the barrel ſuſpended by the pendulous rods *c*, *d*; and *r* is the ribbon for meaſuring the recoil.

The length of the bore is 30 inches, and its diameter is one inch, conſequently it is juſt 30 calibres in length, and will carry a leaden bullet of about 3 ounces.

The barrel may be made of gun metal, or of caſt iron as that is a cheaper commodity; but great care muſt be taken in boring it, to make the cylinder perfectly ſtrait and ſmooth, as well as to preſerve the proper dimenſions. Of whatever metal the barrel is made, it ought to weigh at leaſt 50 lbs. in order that the velocity of the recoil may not be too great; and the rods by which it is ſuſpended ſhould be five feet in length. The vent may be about one twentieth of an inch in diameter; and it ſhould be *bouched* or lined with gold, in the ſame manner as the touch-hole is made in the better kind of fowling pieces, in order that its dimenſions may not be increaſed by repeated firing.

The bullets ſhould be made to fit the bore with very little windage; and it would be better if they were all caſt in the ſame mould, and of the ſame parcel of lead, as in that caſe their weights and dimenſions would be more accurately the ſame, and the experiments would of courſe be more concluſive.

The ſtated charge of powder may be half an ounce, and it ſhould always be put up in a cartridge of very fine paper; and after the piece is loaded it ſhould be primed with other powder, firſt taking care to prick the cartridge by thruſting a priming wire down the vent.

As it appears, from ſeveral experiments made on purpoſe to aſcertain the fact, that ramming the powder more or leſs has a very ſenſible effect to increaſe or diminiſh the force of the charge; to prevent any inaccuracies that might ariſe from that cauſe, a ram-rod, ſuch as is repreſented fig. 15. may be made uſe of. It is to be made of a cylindric piece of wood in the ſame manner as ram-rods in general are made, but with the addition of a ring C, about one inch and a half, or two inches in diameter, which, being placed at a proper diſtance from the end (*a*) of the ram-rod that goes up into the bore, will prevent its being thruſt up too far. This ring may be made of wood, or of any kind of metal as ſhall be found moſt convenient. The other end of the ram-rod (*b*) may be 31 or 32 inches in length from the ring, and the extremity of it being covered with a proper ſubſtance, it may be made uſe of for wiping out the barrel after each experiment.

The machine (*f*) for the tape to ſlide through may be the ſame as is deſcribed by Dr. HUTTON in his account of his experiments on the initial velocities of cannon balls; as his method is much better calculated to anſwer the purpoſe than that propoſed and made uſe of by Mr. ROBINS. It will alſo be better for the axis of the pendulous rods to reſt upon level pieces of wood or iron, than for them to move in circular grooves: only care muſt be taken to confine them by ſtaples or ſome other contrivance, to prevent their ſlipping out of their places.

The trunnions, by means of which the barrel is connected with the pendulous rods, and upon which it is ſupported, ſhould be as ſmall as poſſible, in order to leſſen the friction; and for the ſame reaſon they ſhould be well poliſhed, as well as the grooves that receive them. They need not be caſt upon the barrel, but may be ſcrewed into it after it is finiſhed.

In making the experiments, regard muſt be had to the heat of the barrel, as well as to the temperature of the atmoſphere; for heat and cold, dryneſs and moiſture, have a very ſenſible effect upon gun-powder to increaſe or diminiſh its force. If therefore a very great degree of accuracy is at any time required, it will be beſt to begin by firing the piece two or three times merely to warm it; after which three or four experiments may be made with ſtandard powder, to determine anew the proof mark (for the ſtrength of the ſame powder is different upon different days); and when this is done, the experiments with the powder that is to be proved are to be made, taking care to preſerve the ſame interval of time between the firings, that the heat of the piece may be the ſame in each trial.

If all theſe precautions are taken, and if the bullets are of the ſame weight and dimenſions, powder may be proved by this method with much greater accuracy than has hitherto been done by any of the common methods made uſe of for that purpoſe.

Of the comparative goodneſs, or value, of powder of different degrees of ſtrength.

Let V denote the velocity of the bullet with the ſtronger powder, and put v equal to the velocity with the weaker, when the charges are equal, and the weight and dimenſions of the bullets are the ſame, and when they are diſcharged from the ſame piece. If the charge is augmented when the weaker powder is made uſe of, till the velocity of the bullet is increaſed from v to V, or becomes equal to the velocity with the given charge of the ſtronger powder, the *value* of the charges may then be ſaid to be equal; and conſequently the weaker powder is as much worſe than the ſtronger, or is of leſs value in proportion as the quantity of it required by the pound, to produce the given effect is greater.

But it is well known, that the velocities, with different quantities of the ſame kind of powder, are in the ſub-duplicate ratio of the weights of the charges. The charges, therefore, muſt be as the ſquares of the velocities, and conſequently the charge of the weaker powder muſt be to that of the ſtronger, when the velocities are equal, as VV is to vv. The weaker powder is therefore as much worſe than the ſtronger as VV is greater than vv; or the comparative goodneſs of powder, of different degrees of ſtrength, is as the ſquares of the velocities of the bullets when the charges are equal.

The mean velocity of the bullets, as ſhewn by the pendulum in the 104th and 105th experiments, when the piece was fired with 145 grains of government powder, was 894 feet in a ſecond; and with the ſame quantity of double proof * battle powder (experiment N° 106) the velocity was 990 feet in a ſecond. Now the ſquares of theſe velocities, which, as we juſt obſerved, meaſure the goodneſs of the powder, are to each other as 1 is to 1,2263, or nearly as 5 is to 6.

With 218 grains of government powder, the mean velocity in four experiments (*viz.* the 40th, 41ſt, 42d, and 43d) was 1225 feet in a ſecond; and in the experiment N° 107. when the ſame quantity of double proof battle powder was made uſe of, the velocity was 1380 in a ſecond; and $\overline{1225}^2$ is to $\overline{1380}^2$ as 1 is to 1,2691.

With 290 grains, or half the weight of the bullet in government powder in the 109th, 110th, 111th, and 112th experiments, the mean velocity of the bullet was 1444 feet in a ſecond; but with the ſame quantity of the battle powder (experiment N° 116.) the velocity was 1525 feet in a ſecond; $\overline{1444}^2$ is to $\overline{1525}^2$, as 1 is to 1,1153.

By taking a medium of theſe trials it appears, that double proof battle powder is better than government powder in proportion as 1,2036 is to 1, or nearly as 6 is to 5.

But if, inſtead of weighing the powder, we eſtimate the quantity of the charge by meaſurement, or the ſpace it occupies in the bore of the piece, the comparative ſtrength of battle powder will appear to be conſiderably greater, or its ſtrength will be to that of government powder nearly as 4 is to 3; for the grains of this better kind of powder being more compact and nearly of a ſpherical form, a greater weight of it will lie in any

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* This is called *battle* powder, not becauſe it is uſed in battle or in war; but from *Battle*, the name of a village in Kent, where that kind of powder is made.

given

given ſpace than of government powder, which is formed more looſely, and of various and of very irregular figures.

Now the common price of double proof battle powder, as it is ſold by the wholeſale dealers in that commodity, is at the rate of £. 10 *per* cwt. net, which is juſt two ſhillings by the pound; while government powder is ſold at £. 5 5*s*. *per* hundred, or one ſhilling and $\frac{6}{10}$th of a penny *per* pound; but battle powder is better than government powder only in the proportion of 1,2036 to 1, or of one ſhilling and two pence to one ſhilling and $\frac{6}{10}$th of a penny; battle powder is therefore ſold at the rate of ten pence by the pound, or $41\frac{2}{3}$ *per cent*. dearer than it ought to be; or thoſe, who make uſe of it in preference to government powder, do it at a certain loſs of $41\frac{2}{3}$ *per cent*. of the money that the powder coſts them.

Of the relation of the velocities of bullets to their weights.

According to Mr. ROBINS's theory, when bullets of the ſame diameter, but different weights, are diſcharged from the ſame piece by the ſame quantity of powder, their velocities ſhould be in the reciprocal ſub-duplicate ratio of their weights; but as this theory is founded upon a ſuppoſition that the action of the elaſtic fluid, generated from the powder, is always the ſame in any and every given part of the bore when the charge is the ſame, whatever may be the weight of the bullet; and as no allowance is made for the expenditure of force required to put the fluid itſelf in motion, or for the loſs of it by the vent; it is plain that the theory is defective. It is true, Dr. HUTTON in his experiments found this law to obtain without any great error, and poſſibly it may hold good with ſufficient accuracy in many caſes; for it ſometimes happens that a number of errors or actions, whoſe operations have a contrary tendency, ſo compenſate each other, that their effects when united are not ſenſible. But when this is the caſe, if any one of the cauſes of error is removed, thoſe which remain will be detected.

When any given charge is loaded with a heavy bullet, more of the powder is inflamed in any very ſhort ſpace of time than when the bullet is lighter, and the action of the powder ought of courſe to be greater on that account; but then a heavy bullet takes up more time in paſſing through the bore than a light one, and conſequently more of the elaſtic fluid, generated from the powder, eſcapes by the vent and by windage. It may happen, that the augmentation of the force, on account of one of theſe circumſtances, may exactly counterbalance the diminution of it ariſing from the other; and if it ſhould be found upon trial that this is the caſe in general, in pieces as they are now conſtructed, and with all the variety of ſhot that are made uſe of in practice, it would be of great uſe to know the fact: and poſſibly it might anſwer as well, as far as it relates to the art of gunnery, as if we were perfectly acquainted with, and were able to appreciate, the effect of each varying circumſtance under which an experiment can be made. But when, concluding too haſtily from the reſult of a partial experiment, we ſuppoſe with Mr. ROBINS, that becauſe the ſum total of the action or preſſure of the elaſtic fluid upon the bullet, during the time of its paſſage through the bore, happens to be the ſame when bullets of different weights are made uſe of (which collective preſſure is in all caſes proportional to, and is accurately meaſured by, the velocity, or rather motion, communicated to the bullet) that therefore the preſſure in any given part is always exactly the ſame, when the quantity of powder is the ſame with which the piece is fired; and from thence endeavour to prove, that the inflammation of gun-powder is inſtantaneous, or that the whole charge is in all caſes inflamed, and "converted into an elaſtic fluid before the bullet is ſenſibly moved "from its place;" ſuch reaſonings and concluſions may lead to very dangerous errors.

It is undoubtedly true, that if the principles aſſumed by Mr. ROBINS with reſpect to the manner in which gun-powder takes fire, and the relation of the elaſticity of the generated fluid to its denſity, or the intenſity of its preſſure upon the bullet as it expands in the barrel, were juſt, and if the loſs of force by the vent and windage was in all caſes inconſiderable, or if it was prevented, the deductions from the theory reſpecting the velocities of bullets of different weights would always hold good. But if, on the contrary, it ſhould be found upon making the experiments carefully, and in ſuch a manner as intirely to prevent inaccuracies ariſing from adventitious circumſtances, that the velocities obſerve a law different from that which the theory ſuppoſes, we may fairly conclude, that the principles upon which the theory is founded are erroneous.

Let us now ſee how far theſe experiments differ from the theory. Thoſe numbered from 84 to 92 incluſive were made in ſuch a manner that no part of the force of the powder was loſt by the vent, or by windage, as has already been mentioned, and all poſſible attention was paid to every circumſtance that could contribute to render them perfect and concluſive.

A particular account of them with the means uſed for forming the bullets, and making them fit for the bore, and the contrivance for preventing the eſcape of the elaſtic fluid by the vent, &c. may be ſeen in the general table, p. 245. The following table ſhews the reſult of them.

N. B. The charge of powder was the ſame in each experiment, and conſiſted of 145 grains in weight.

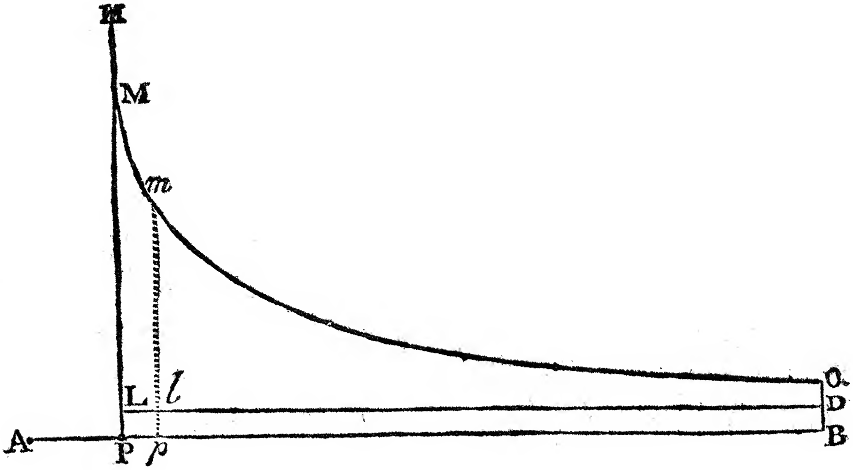
	Weight of the bullet.	Velocity of the bullet.		Difference.
		Actual.	Computed.	
85th exp.	90 grs.	2109	2109	——
86th	251	1430	1262	+168
87th	354	1288	1063	+225
88th	600	1240	817	+423
89th	603	1224	815	+409
90th	1184	1017	581	+436
91ſt	1754	893	478	+415
92d	2352	812	413	+399

The computed velocities, as they are ſet down in this table, were determined from the actual velocity of the bullet, as determined by the recoil in the 85th experiment; and the reciprocal ſub-duplicate ratio of its weight to the weight of the bullet in each ſubſequent experiment; and in the laſt column is marked the difference between the experiment and the theory, or the number of feet in a ſecond, by which the actual velocity exceeds the computed.

But in order that we may ſee this matter in different points of view, let the order of the experiments be now inverted, and let the computed velocities be determined from the actual velocity in the 92d experiment; and aſſuming the total or collective preſſure exerted by the powder upon the bullet in that experiment equal to unity, let the collective preſſure in the other experiments be computed from the ratio of the actual to the computed velocities, and the table will ſtand thus:

	Weight of the bullet.	Velocity of the bullet		Difference.	Collective preſſure.
		Actual.	Computed.		
92d exp.	2352 grs.	812	812	—	1,0000
91ſt	1754	893	940	− 47	0,9020
90th	1184	1017	1145	− 128	0,7897
89th	603	1224	1604	− 380	0,5825
88th	600	1240	1608	− 368	0,5949
87th	354	1288	2093	− 805	0,3778
86th	251	1430	2486	− 1056	0,3310
85th	90	2109	4151	− 2042	0,2581

In the following figure let AB repreſent the axis of the piece, and AP the length of the ſpace filled with powder; and at the point P let the perpendicular PH be erected, upon which let PL and PM be taken from P towards H of ſuch magnitudes that while PL expounds the uniform force of gravity, or the weight of the bullet, PM ſhall be as the force exerted by the powder



upon the bullet at the moment of the exploſion. If now we ſuppoſe, that while the bullet moves on from P towards B, the line PM or *pm*, goes along with it, and that the point *m* is always taken in ſuch a manner that the line *pm*, ſhall be to *pl*, or PL, as the force acting upon the bullet in the point *p*, is to its weight, till *pm*, coincides with QB, then will the area PMQB be to the area PLDB in the duplicate proportion of the velocities which the bullet would acquire when acted on by its own gravity through the ſpace PB, and when impelled through the ſame ſpace by the force of the powder, as may be ſeen demonſtrated by Sir ISAAC NEWTON, in his Mathematical Principles of Natural Philoſophy, book I. prop. 39.

Now what I call the collective preſſure, or ſum total of the action of the powder upon the bullet, is the meaſure of the area PMQB; and it is plain, from what has been ſaid above, that its meaſures are in all caſes to be accurately determined, when the weight and velocity of the bullet are known.

If all the powder of the charge was inflamed at once, or before the bullet ſenſibly moved from its place; and if the preſſure of the generated fluid was always as its denſity, or inverſely as the ſpace it occupies, then would the line MQ be an hyberbola, the area PMQB would always be the ſame when the charge was the ſame, and conſequently the velocities of the bullets would be as the ſquare roots of their weights inverſely. But it appears, from the before mentioned experiments, that when the weight of the bullet was increaſed four times, the action of the powder, or area PMQB, was nearly doubled; for in the 92d experiment, when four bullets were diſcharged at once, the collective preſſure was as 1; but in the 89th experiment, when a ſingle bullet was made uſe of, the collective preſſure was only as 0,5825; and in the 85th, 86th, and 87th experiments, when the bullets were much lighter, the action of the charge was ſtill leſs.

But though we can determine with great certainty, from theſe experiments, the ratio in which the action of the powder upon the bullet was increaſed or diminiſhed, by making uſe of bullets of greater or leſs weight; yet we cannot from thence aſcertain the relation of the elaſticity of the generated fluid to its denſity, nor the quantity of powder that is inflamed at different periods before and after the bullet begins to move in the bore.

But aſſuming Mr. ROBINS's principles as far as relates to the elaſticity of the fluid, and ſuppoſing that in all the experiments, except the 92d, a part only of the charge took fire, and that that part was inflamed and converted into an elaſtic fluid before the bullet began to move; upon that ſuppoſition we can determine the quantity of powder that took fire in each experiment; for the quantity of powder in that caſe would be as the collective preſſure.

Thus, if the whole charge, = 145 grains in weight, is ſuppoſed to have been inflamed in the 92d experiment, the quantity inflamed in each of the other experiments will appear to have been as follows; *viz.*

	Weight of the bullet.	Velocity of the bullet.	Collective preſſure.	Powder inflamed.
85th exp.	90 grs.	2109	0,2581	37 grs.
86th	251	1430	0,3310	48
87th	354	1288	0,3778	55
88th	600	1240	0,5949	86
89th	603	1224	0,5825	84
90th	1184	1017	0,7897	114
91ſt	1754	893	0,9020	131

But there are many reaſons to ſuppoſe, that the diminution of the action of the powder upon the bullet, when it is lighter, is not ſo much owing to the ſmalleſs of the quantity of powder that takes fire in that caſe as to the *vis inertiæ* of the generated fluid. It is true, that a greater portion of the charge takes fire when the bullet is heavy than when it is light, as I found in the very experiments of which I am now ſpeaking; but then the quantity of unfired powder in any caſe was much too ſmall to account for the apparent diminution of the force when light bullets were made uſe of.

If the elaſtic fluid, in the action of which the force of powder conſiſts, were infinitely fine, or if its weight bore no proportion to that of the powder that generated it; and if the groſs matter, or *caput mortuum*, of the powder remained in the bottom of the bore after the exploſion, then, and upon no other ſuppoſition, would the preſſure upon the bullet be inverſely as the ſpace occupied by the fluid: but it is evident that this can never be the caſe.

A curious ſubject for ſpeculation here occurs: how far would it be advantageous, were it poſſible, to diminiſh the ſpecific gravity of gun-powder, and the fluid generated from it, without leſſening its elaſtic force? It would certainly act upon very light bullets with greater force; but when heavy ones came to be made uſe of, there is reaſon to think, that, except extraordinary precaution was taken to prevent it, the greateſt part of the force would be loſt by the vent and by windage.

The velocity with which elaſtic fluids ruſh into a void ſpace is as the elaſticity of the fluid directly, and inverſely as its denſity; if, therefore, the denſity of the fluid generated from powder was four times leſs than it is, its elaſticity remaining the ſame, it would iſſue out at the vent, and eſcape by the ſide of the bullet in the bore, with nearly four times as great a velocity as it does at preſent; but we know from experiment that the loſs of force on thoſe accounts is now very conſiderable.

In the experiments N° 76. and 77. when the piece was fired with 145 grains of powder, the velocity of the bullets at a medium was 1040 feet in a ſecond; but in the 88th and 89th experiments, when the bullets were even heavier, and the piece was fired with the ſame quantity of powder, the mean velocity was 1232 feet in a ſecond. The difference = 192 feet in a ſecond, anſwers to a difference of force greater in the laſt experiments than in the firſt in the proportion of 14 to 10.

I know of no way to account for this difference, but by ſuppoſing that it was owing intirely to the eſcape of the elaſtic fluid by the vent, and by windage, in thoſe experiments where the vent was open, and the bullets were put naked into the piece.

An elaſtic bow, made of very light wood, will throw an arrow, and eſpecially a light one, with greater velocity than a bow of ſteel of the ſame degree of ſtiffneſs: but, for practice, I think it is plain, that gun-powder may *be ſuppoſed* to be ſo light as to be rendered intirely uſeleſs: and for ſome purpoſes it ſeems probable, that it would not be the worſe for being even heavier than it is now made. Vents are abſolutely neceſſary in fire-arms, and in large pieces the windage muſt be conſiderable, in order that the bullets, which are not always ſo round as they ſhould be, may not ſtick in the bore; and thoſe who have been preſent at the firing of heavy artillery and large mortars with ſhot and ſhells, muſt have obſerved, that there is a ſenſible ſpace of time elapſes between the lighting of the prime and the exploſion; and that, during that interval, the flame is continually iſſuing out at the vent with a hiſſing noiſe, and with a prodigious velocity, as appears by the height to which the ſtream of fire mounts up in the air. It is plain, that this loſs muſt be greater in proportion as the ſhot that is diſcharged is heavier; and I have often fancied, that I perceived a ſenſible difference in the time that elapſed between the firing of the prime and the exploſion, when bullets were diſcharged, and when the piece has been fired with powder only; the time being apparently longer in the former caſe than the latter.

Almoſt all the writers upon gun-powder, and particularly thoſe of the laſt century, gave different recipes for powder that is deſigned for different uſes. Thus the French authors mention *poudre à mouſquet*, *poudre ordinaire de guerre*, *poudre de chaſſe*, and *poudre d'artifice*; all of which are compoſed of ſalt petre, ſulphur, and charcoal, taken in different proportions. Is it not probable, that this variety in the compoſition of powder was originally introduced in conſequence of obſervation that one kind of powder was better adapted for particular purpoſes than another, or from experiments made on purpoſe to aſcertain the fact? There is one circumſtance that would lead us to ſuppoſe that that was the caſe.— That kind of powder which was deſigned for great guns and mortars was weaker than thoſe which were intended to be uſed in ſmaller pieces: for if there is any foundation for theſe conjectures, it is certain, that the weakeſt powder, or the heavieſt in proportion to its elaſtic force, ought to be uſed to impel the heavieſt bullets, and particularly in guns that are imperfectly formed, where the vent is large, and the windage very great.

I am perfectly aware, that an objection may here be made, viz. that the elaſtic fluid, which is generated from gun-powder, muſt be ſuppoſed to have the ſame properties very nearly, whatever may be the proportion of the ſeveral ingredients, and that therefore the only difference there can be in powder is, that one kind may generate more of this fluid, and another leſs; and that when it is generated, it acts in the ſame manner, and will alike eſcape, and with the ſame velocity, by any paſſage it can find. But to this I anſwer, though the fluid may be the ſame, as undoubtedly it is, and though its denſity and elaſticity may be the ſame in all caſes at the inſtant of its generation, yet in the exploſion, the elaſtic and un-elaſtic parts are ſo mixed and blended, that I imagine the fluid cannot expand without taking the groſs matter along with it, and the velocity with which the flame iſſues out at the vent is to be computed from the elaſticity of the fluid, and the denſity or weight of the fluid and the groſs matter taken together, and not ſimply from the elaſticity and denſity of the fluid. If antimony in an impalpable powder, or any other heavy body, was intimately mixed with water in a veſſel of any kind, and kept in ſuſpenſion by ſhaking or ſtirring them about; and if a hole was opened in the ſide or bottom of the veſſel, the water would not run out without taking the particles of the ſolid body along with it. And in the ſame manner I conceive the ſolid particles that remain after the exploſion of gun-powder are carried forward with the generated elaſtic fluid, and being carried forward retard its motion.— But to return from this digreſſion.

As it appears from theſe experiments, that the relation of the velocities of bullets to their weights is different from that which Mr. ROBINS's theory ſuppoſes, it remains to inquire what the law is which actually obtains. And, firſt, as the velocities bear a greater proportion to each other than the reciprocal ſub-duplicate ratio of the weights of the bullets, let us ſee how near they come to the reciprocal ſub-triplicate ratio of their weights.

		Velocity of the bullet				
	Weight of the bullet.	Computed.		Actual.		Computed.
		Recip. ſub-dup. ratio.	Error of the theory.		Error of the theory.	Recip. ſub-trip. ratio.
92d	2352	812	——	812	——	812
91ſt	1754	940	+ 47	893	+ 2	895
90th	1184	1145	+ 128	1017	+ 4	1021
89th	603	1604	+ 380	1224	+ 54	1278
88th	600	1608	+ 368	1240	+ 40	1280
87th	354	2093	+ 805	1288	+239	1527
86th	251	2486	+1056	1430	+282	1712
85th	90	4151	+2042	2109	+301	2410

Here the velocities computed upon the laſt ſuppoſition appear to agree much better with the experiments than thoſe computed upon Mr. ROBINS's principles; but ſtill there is a conſiderable difference between the actual and the computed velocities in the three laſt experiments in the table.

As the powder itſelf is heavy, it may be conſidered as a weight that is put in motion along with the bullet; and if we ſuppoſe the denſity of the generated fluid is always uniform from the bullet to the breech, the velocity of the center of gravity of the powder or (which amounts to the ſame thing) of the elaſtic fluid, and the groſs matter generated from it will be juſt half as great as the velocity of the bullet. If therefore we put P to denote the weight of the powder, B the weight of the bullet, and v its initial velocity; then $Bv + \frac{1}{2}Pv = \overline{B + \frac{1}{2}P} \times v$ will expreſs the *momentum* of the charge at the inſtant when the bullet quits the bore.

If now, inſtead of aſcertaining the relation of the velocities to the weights of the bullets, we add half the weight of the powder to the weight of the bullet, and compute the velocities from the reciprocal ſub-triplicate ratio of the quantity $\overline{B + \frac{1}{2}P}$ in each experiment, the table will ſtand thus:

	Weight of the bullet and half the powder.	Velocity of the bullet.		Error of the theory.
		Actual.	Computed.	
	$\overline{B + \frac{1}{2}P} =$			
92d exp.	$\overline{2352 + 72\frac{1}{2}}$	812	812	—
91ſt	$\overline{1754 + 72\frac{1}{2}}$	893	892	− 1
90th	$\overline{1184 + 72\frac{1}{2}}$	1017	1011	− 6
89th	$\overline{603 + 72\frac{1}{2}}$	1224	1243	+ 19
88th	$\overline{600 + 72\frac{1}{2}}$	1240	1245	+ 5
87th	$\overline{354 + 72\frac{1}{2}}$	1288	1449	+ 161
86th	$\overline{251 + 72\frac{1}{2}}$	1430	1589	+ 159
85th	$\overline{90 + 72\frac{1}{2}}$	2109	1999	− 110

The agreement between the actual and computed velocities is here very remarkable, and particularly in the five firſt experiments, which are certainly thoſe upon which the greateſt dependence may be placed.

And hence we are enabled to determine the natures of the *mn*, and *gf* (fig. 16.); for ſince B (which expreſſes the weight of the bullet) is as the length taken from A towards B in the figure in the ſeveral experiments; and as the velocities are as the lines drawn perpendicular to the line AB from the places where thoſe lengths terminate, as *w*, *u*, &c. ending at the curve *m*, *n*; if we put $a=\frac{1}{2}P$, $x=B$, and $y=wu$; then will the relation of x and y be defined by this equation $\frac{1}{\sqrt{a+x^3}}=y$. And if z be put to denote the line $w\,r$, and o, the recoil when the given charge is fired without any bullet, it will be $\frac{x}{\sqrt{a+x^3}}+b=z$ in the curve *gf*, x being the abſciſſa, and z the correſponding ordinate to the curve.

In the 92d experiment half the weight of the powder $(=a)$ was 72½ grains; the weight of the bullet was 2352 grains $(=x)$; the recoil $(=z)$ was 32,25 inches, and with the given charge without any bullet the recoil $(=b)$ was 4,4 inches; if now from theſe *data*, and the known weight of the bullet in each of the other experiments in this ſet, the recoil be computed by means of the theorem $\frac{x}{\sqrt{a+x^3}}+b=z$, we ſhall ſee how the reſult of thoſe experiments agrees with this theory: thus,

	Weight of the bullet.	Recoil Actual.	 Computed.	Difference.
92d exp.	2352	32,25	32,25	——
91ſt	1754	27,18	27,22	+0,04
90th	1184	21,92	21,85	−0,07
89th	603	15,13	15,33	+0,2
88th	600	15,22	15,29	+0,07
87th	354	11,03	11,87	+0,84
86th	251	9,62	10,21	+0,59
85th	90	7,16	7,02	−0,14
84th and 93d	0	4,4	4,4	——

Here the agreement of the actual and computed recoils is as remarkable as that of the actual and computed velocities in the foregoing table.

By the figure 17. may be ſeen at one view the reſult of all theſe experiments and computations. The numbers upon the line AB (as in the fig. 16.) repreſent the weights of the bullets, while the lines drawn from thoſe numbers perpendicular to AB on each ſide, and ending at the curves *m*, *n*, are as the velocities of the bullets in the ſeveral experiments; the line AB being the axis of the curves, the lengths taken from A to the different numbers towards B ($=x$) the abſciſſa, and the perpendiculars ($=y$) the correſponding ordinates. The ordinates to the the curve *hn*, are as the velocities computed from the theorem $\frac{1}{\sqrt{a+x^3}}=y$, and the ordinates to the curve *p*, *n* (which is the logarithmic curve, as it is $\frac{1}{\sqrt{x}}=y$) ſhew the velocities computed upon Mr. ROBINS's principles. The curve *gf* is drawn from the theorem $\frac{x}{\sqrt{a+x^3}}+b=z$; and the actual recoil is marked upon the ordinates to this curve by large round dots, which in all the experiments, except the 86th and 87th, very nearly coincide with the curve.

In the fig. 18. the numbers upon the line AB, taken from A, denote the different charges of powder uſed in the courſe of the experiments, while the ordinates to the curve *cd*, expreſs the velocities of the bullets, with the vent at o. The lines drawn perpendicular from the line AB to the line *ef*, repreſent the recoil with the ſeveral charges of powder, and a leaden bullet; and the portion of thoſe lines that is comprehended between the line AB and the line *gh*, denotes the recoil when the given charge was fired without any bullet.

Having now ſhewn by experiment the relation of the velocities of bullets to their weights, when care is taken to prevent intirely the loſs of force by the eſcape of the elaſtic fluid through the vent and by the windage, I ſhall leave it to mathematicians to determine from theſe *data* the properties of that fluid.

But, before I take my leave of this ſubject, I would juſt obſerve, that Mr. ROBINS is not only miſtaken in the principle he aſſumes, reſpecting the relation of the elaſticity of the fluid generated from gun-powder to its denſity, or rather the law of its action upon the bullet as it expands in the bore; but his determination of the force of gun-powder is alſo erroneous, even upon his own principles: for he determines its force to be 1000 times greater than the mean preſſure of the atmoſphere; whereas it appears, from the reſult of the 92d experiment, that its force is at leaſt 1308 times greater than the mean preſſure of the atmoſphere, as will be evident to thoſe who will take the trouble to make the computation.

Of an attempt to determine the exploſive force of aurum fulminans, *or a compariſon between its force and that of gun-powder.*

Having provided myſelf with a ſmall quantity of this wonderful powder, upon the goodneſs of which I could depend, I endeavoured to aſcertain its exploſive force by making uſe of it inſtead of gun-powder for diſcharging a bullet, and meaſuring, by means of the pendulum, the velocity which the bullet acquired; and concluding, from the tremendous report with which this ſubſtance explodes, that its elaſtic force was vaſtly greater than that of gun-powder, I took care to have a barrel provided of uncommon ſtrength, on purpoſe for the experiment. Its length in the bore is 13,25 inches, the diameter of the bore is 0,55 of an inch, and its weight 7 lbs. 2 oz. It is of the beſt iron, and was made by WOGDON; and the accuracy with which it is finiſhed does credit to the workman.

This barrel being charged with one ſixteenth of an ounce (= 27,34 grains) of *aurum fulminans* and two leaden bullets, which, together with the leather that was put about them to make them fit the bore without windage, weighed 427 grains; it was laid upon a chaffing-diſh of live coals, at the diſtance of about 10 feet from the pendulum, and againſt the center of the target of the pendulum the piece was directed.

Having ſecured the barrel in ſuch a manner that its direction ſhould not alter, I retired to a little diſtance, in order to be out of danger in caſe of an accident, where I waited in anxious expectation the event of the exploſion.

I had remained in this ſituation ſome minutes, and almoſt deſpaired of the experiment's ſucceeding, when the powder exploded, but with a report infinitely leſs than what I expected, the noiſe not greatly exceeding the report of a well-charged wind gun; and it was not till I ſaw the pendulum in motion that I could be perſuaded that the bullets had been diſcharged. I found, however, upon examination, that nothing was left in the barrel, and from the great number of ſmall particles of revived metal that were diſperſed about, I had reaſon to think that all the powder had exploded.

The bullets ſtruck the pendulum nearly in the center of the target, and both of them remained in the wood: and I found, upon making the calculation, that they had impinged againſt it with a velocity of 428 feet in a ſecond.

If we now ſuppoſe that the force of *aurum fulminans* ariſes from the action of an elaſtic fluid that is generated from it in the moment of its exploſion, and that the elaſticity of this fluid, or rather the force it exerts upon the bullet as it goes on to expand, is always as its denſity, or inverſely as the ſpace it occupies; then, from the known dimenſions of the barrel, the length of the ſpace occupied by the charge (which in this experiment was 0,47 of an inch), and the weight and velocity of the bullets, the elaſtic force of this fluid at the inſtant of its generation may be determined: and I find, upon making the calculation upon theſe principles, that its force turns out 307 times greater than the mean elaſtic force of common air.

According to Mr. ROBINS's theory, the elaſtic force of the fluid generated from gun-powder in its inflammation is 1,000 times greater than the mean preſſure of the atmoſphere; the force of *aurum fulminans*, therefore, appears to be to that of gun-powder as 307 is to 1,000, or as 4 is to 13 very nearly.

Of the ſpecific gravity of gun-powder.

To determine the ſpecific gravity of gun-powder I made uſe of the following method. A large glaſs bucket, with a narrow mouth, being ſuſpended to one of the arms of a very nice balance, and exactly counter-poiſed by weights put in the oppoſite ſcale, it was filled firſt with government powder poured in lightly, then with the ſame powder ſhaken well together, afterwards with powder and water together, and laſtly with water alone, and in each caſe the contents of the bucket were very exactly weighed.

The ſpecific gravity of gun-powder, as determined from theſe experiments, is as follows:

Specific gravity of rain water - -	1,000
Government powder, as it lies light in a heap, mixed with air - - - -	0,836
Government powder well ſhaken together -	0,937
The ſolid ſubſtance of the powder - -	1,745

Hence it appears, that a cubic inch of government powder ſhaken well together weighs juſt 243 grains; that a cubic inch of ſolid powder would weigh 442 grains; and, conſequently, that the interſtices between the particles of the powder, as it is grained for uſe, are nearly as great as the ſpaces which thoſe particles occupy.

MISCELLANEOUS EXPERIMENTS.

Of ſome unſucceſsful attempts to increaſe the force of gun-powder.

It has been ſuppoſed by many, that the force of ſteam is even greater than that of gun-powder; and that if a quantity of water, confined in the chamber of a gun, could at once be rarified into ſteam, it would impel a bullet with prodigious velocity. Several attempts have been made to ſhoot bullets in this manner; but I know of none that have ſucceeded; at leaſt ſo far as to render it probable that water can ever be ſubſtituted in the room of gun-powder for military purpoſes, as ſome have imagined.

The great difficulty that attends making theſe experiments lies in finding out a method by which the water can at once be rarified, and converted into elaſtic ſteam; and it occurred to me, that poſſibly that might be effected by means of gun-powder, by confining a ſmall quantity of water in ſome very thin ſubſtance, and ſurrounding and incloſing it with powder, and afterwards ſetting fire to the charge. The method I took to do this was as follows. Having procured a number of air bladders of very ſmall fiſhes, I put different quantities of water into them from the ſize of a ſmall pea to that of a ſmall piſtol bullet, and tying them up cloſe with ſome very fine thread, I hung up theſe little globules in the open air till they were quite dry on the outſide. I then provided a number of cartridges made of fine paper, and filled them with a known quantity of powder, equal to the cuſtomary charge for a common horſeman's piſtol; and having loaded ſuch a piſtol with one of them and a fit bullet, I laid it down upon the ground, and directing it againſt an oaken plank that was placed about ſix feet from the muzzle, I fired it off by a train, and carefully obſerved the recoil, and alſo the penetration of the bullet. I then took ſeveral of the filled cartridges that remained, and pouring out part of the powder, I put one or more of the little bladders filled with water in the center of the cartridge, and afterwards pouring back the remaining part of the charge, confined the water in the midſt of the powder.

With theſe cartridges and a fit bullet, the piſtol was ſucceſſively loaded, and being placed upon the ground as before, and fired by a train, the recoil, and the penetration of the bullets were obſerved; and I conſtantly found, that the force of the charge was very ſenſibly diminiſhed by the addition of the globule of water, and the larger the quantity of water was that was thus confined, the leſs was the effect of the charge; neither the recoil of the piſtol, nor the penetration of the bullet, being near equal to what they were when the given quantity of powder was fired without the water; and the report of the exploſion appeared to be leſſened in a ſtill greater proportion than the recoil or penetration.

Concluding that this diminution of the force of the charge aroſe from the burſting of the little bladder, and the diſperſion of the water among the powder before it was all inflamed, by which a great part of it was prevented from taking fire, I repeated the experiments with highly rectified ſpirits of wine inſtead of water; but the reſult was nearly the ſame as before: the force of the charge was conſtantly and very ſenſibly diminiſhed. I afterwards made uſe of etherial oil of turpentine, and then of ſmall quantities of quickſilver; but ſtill with no better ſucceſs. Every thing I mixed with the powder, inſtead of increaſing, ſerved to leſſen the force of the charge.

Theſe trials were all made ſeveral months before I began the courſe of my experiments upon gun-powder, which I have already given an account of; and though they were altogether unſucceſsful, yet I reſumed the inquiry at that time, and made ſeveral new experiments, with a view to find out ſomething that ſhould be ſtronger than powder, or which, when mixed with it, ſhould increaſe its force.

It is well known, that the elaſtic force of quickſilver converted into vapour is very great; this ſubſtance I made uſe of in my former trials, as I have juſt obſerved, but without ſucceſs. I thought, however, that the failure of that attempt might poſſibly be owing to the quickſilver being too much in a body, by which means the fire could not act upon it to the greateſt advantage; but that if it could be divided into exceeding ſmall particles, and ſo ordered that each particle might be completely ſurrounded by, and expoſed to, the action of the flame of the powder, it would be very ſoon heated, and poſſibly might be converted into an elaſtic ſteam or vapour, before the bullet could be ſenſibly removed from its place. To determine this point I mixed 20 grains of æthiops mineral very intimately with 145 grains of powder, and charging the piece with this compound, it was loaded with a fit bullet and fired; but the force of the charge was leſs than that which the powder alone would have exerted, as appears by comparing the 76th and 77th experiments with the 79th.

Common *pulvis fulminans* is made of one part of ſulphur, two parts of ſalt of tartar, and three parts of nitre; and if we may judge by the report of the exploſion, the elaſtic force of this compound is conſiderably greater than that of gun-powder.

I was willing to ſee the effect of mixing ſalt of tartar with gun-powder, and accordingly having provided ſome of this alkaline ſalt in its pureſt ſtate, thoroughly dry, and in a fine powder, I mixed 20 grains of it with 145 grains of gun-powder; and upon diſcharging a bullet with the mixture, I found that the alkaline ſalt had conſiderably leſſened the force of the powder. See experiment N° 78.

I next made uſe of *ſal ammoniacum*. That ſalt has been found to produce a very large quantity of elaſtic air, or vapour, when expoſed to heat under certain circumſtances; but when 20 grains of it were mixed with a charge of gun-powder, inſtead of adding to its force, it diminiſhed it very ſenſibly. See the 80th experiment.

Moſt, if not all, the metals, are thought to produce large quantities of air when they are diſſolved in proper *menſtrua*, and particularly braſs, when it is diſſolved in ſpirit of nitre. Deſirous of ſeeing if this could be done by the flame, or acid vapour of fired powder, I mixed 20 grains of braſs in a very fine powder, commonly called braſs duſt (being the ſmall particles of this metal that fly off from the wheel in ſharpening pins), with 145 grains of powder, and with this compound and a fit bullet I loaded my barrel and diſcharged it; but the experiment (N° 81.) ſhewed, that the force of the powder was not increaſed by the addition of the braſs duſt, but the contrary.

It ſeems probable, however, that neither braſs duſt nor æthiops mineral are of themſelves capable of diminiſhing the force of gun-powder in any conſiderable degree, otherwiſe than, by filling up the interſtices between the grains, and obſtructing the paſſage of the flame, and ſo impeding the progreſs of the inflammation. And hence it appears, how earthy particles and

impurities

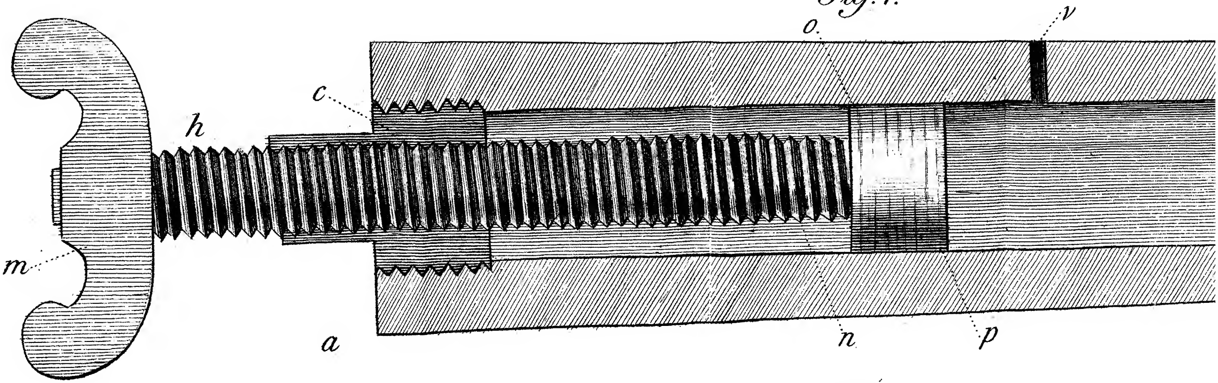
impurities of all kinds are ſo very detrimental to gun-powder. It is not that they deſtroy or alter the properties of any of the bodies of which the powder is compoſed, but ſimply, that by obſtructing the progreſs of the inflammation, they leſſen its force, and render it of little or no value. Too much care, therefore, cannot be taken in manufacturing powder to free the materials from all heterogeneous matter.

Of an attempt to ſhoot flame inſtead of bullets.

Having often obſerved paper and other light bodies to come out of great guns and ſmall arms inflamed, I was led to try if other inflammable bodies might not be ſet on fire in like manner, and particularly inflammable fluids; and I thought if this could be effected, it might be poſſible to project ſuch ignited bodies by the force of the exploſion, and by that means communicate the fire to other bodies at ſome conſiderable diſtance; but in this attempt I failed totally. I never could ſet dry tow on fire at the diſtance of five yards from the muzzle of my barrel. I repeatedly diſcharged large wads of tow and paper, thoroughly ſoaked in the moſt inflammable fluids, ſuch as *alkohol*, *ætherial ſpirit of turpentine*, *balſam of ſulphur*, &c.; but none of them were ever ſet on fire by the exploſion. Sometimes I diſcharged three or four ſpoonfuls of the inflammable fluid, by interpoſing a very thin wad of cork over the powder, and another over the fluid; but ſtill with no better ſucceſs. The fluid was projected againſt the wall as before, and left a mark where it hit; but it never could be made to take fire; ſo I gave up the attempt. If it had ſucceeded, probably it would have turned out one of the moſt important diſcoveries in the art of war that have been made ſince the invention of gun-powder.

⁂

Fig. 1.



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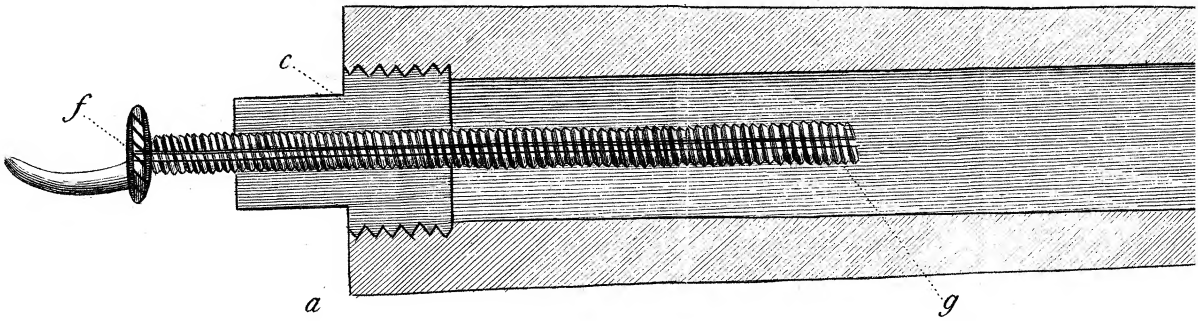

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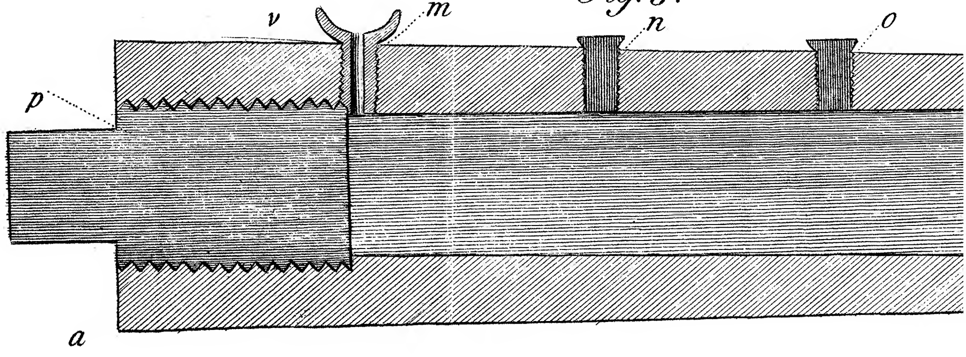

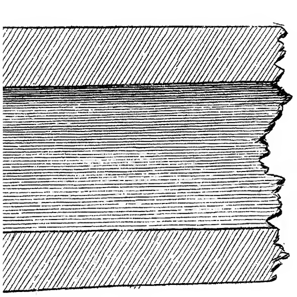

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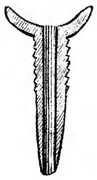

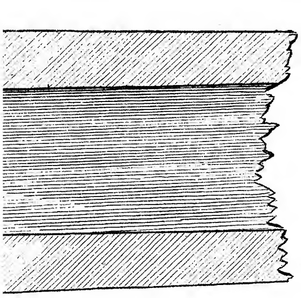

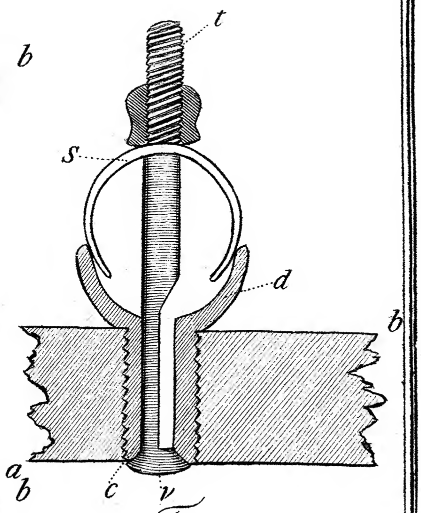

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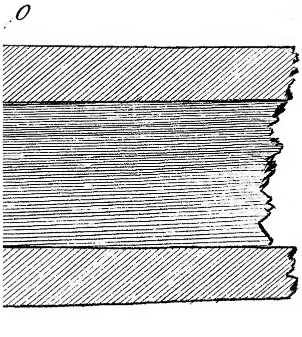

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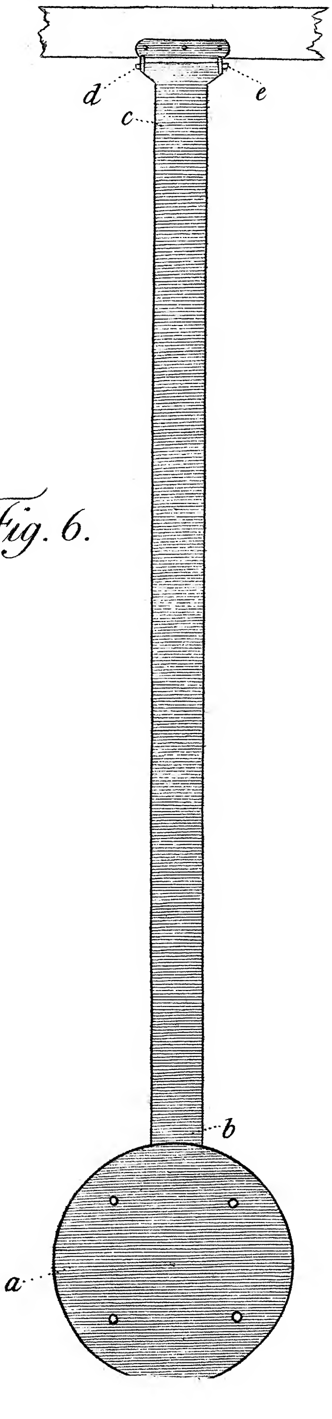

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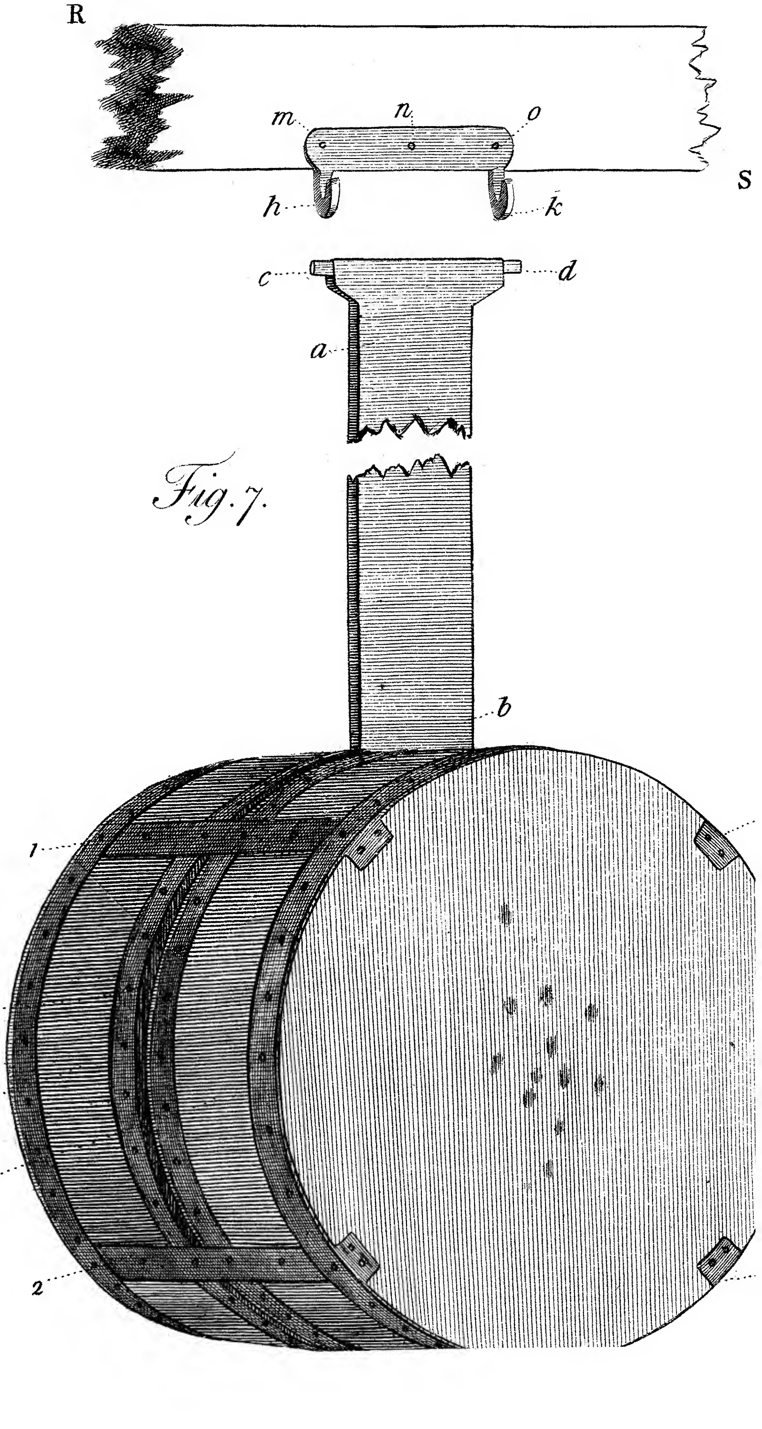

Fig. 7.

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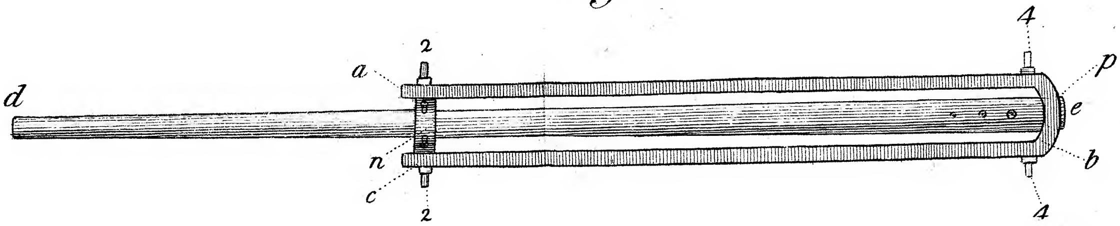
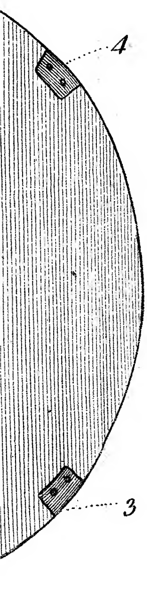
Fig. 8.





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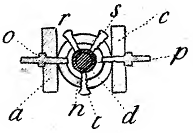

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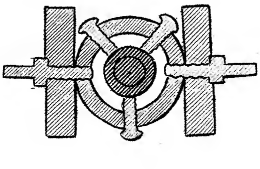

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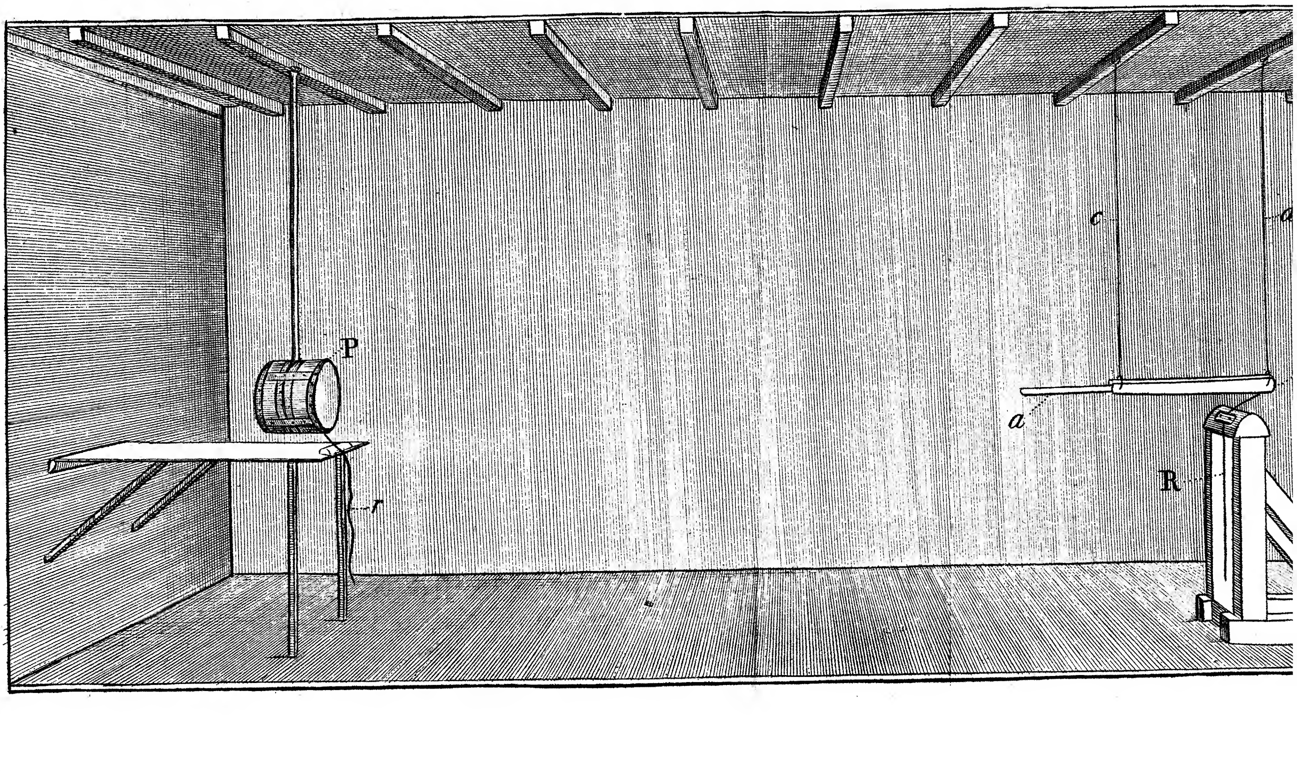

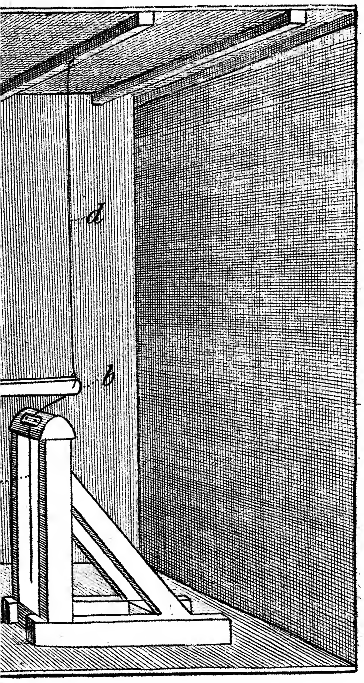

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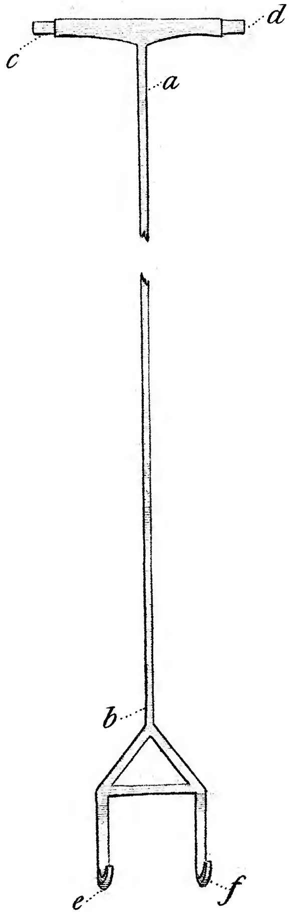

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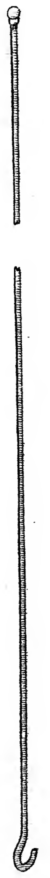

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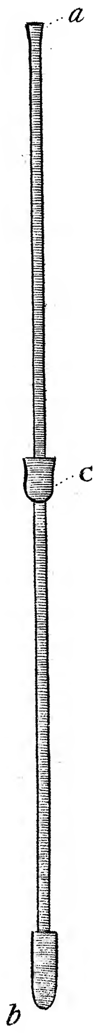

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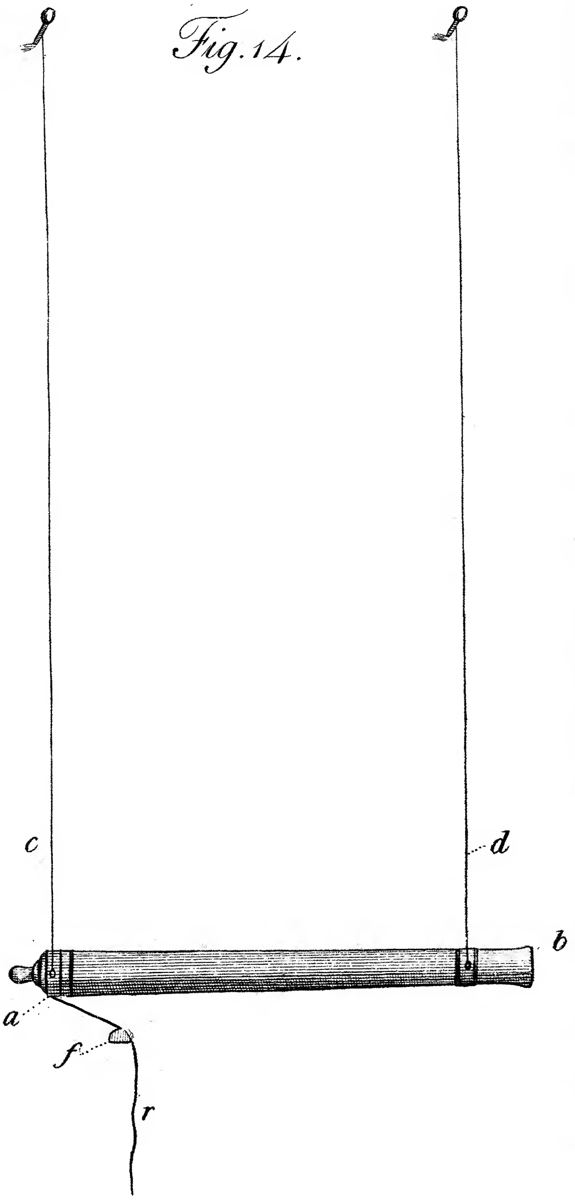

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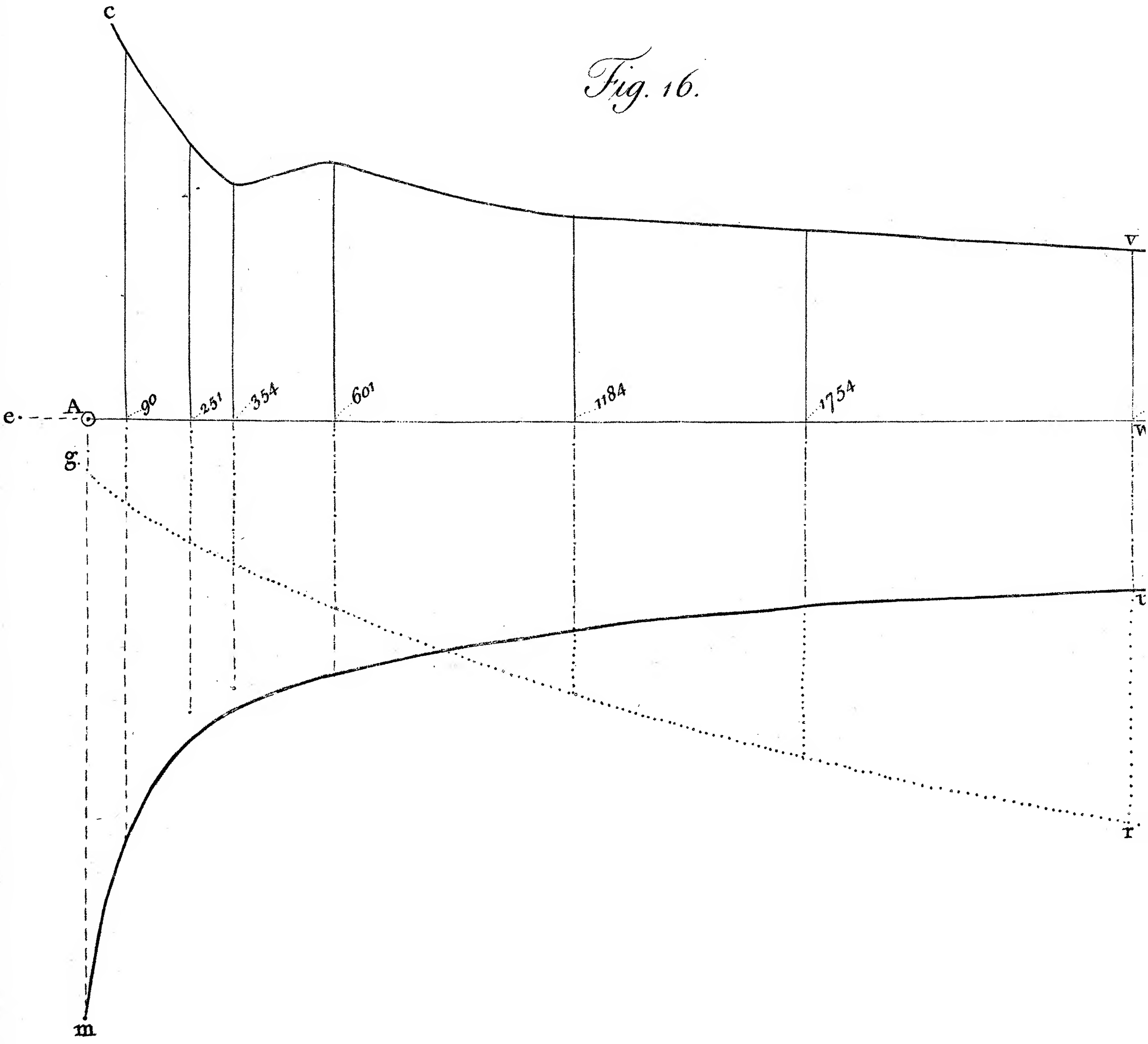

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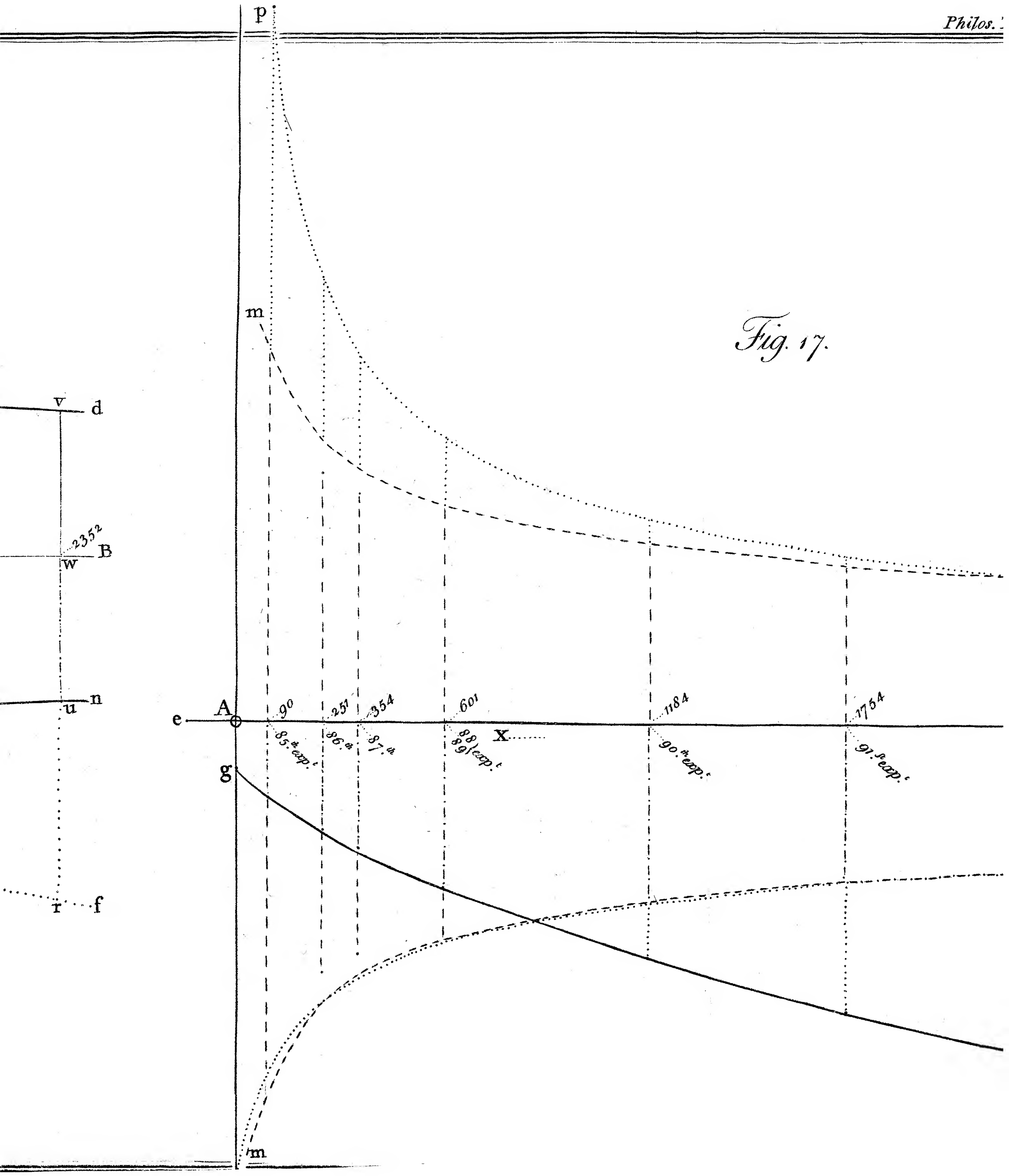
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Fig. 17.

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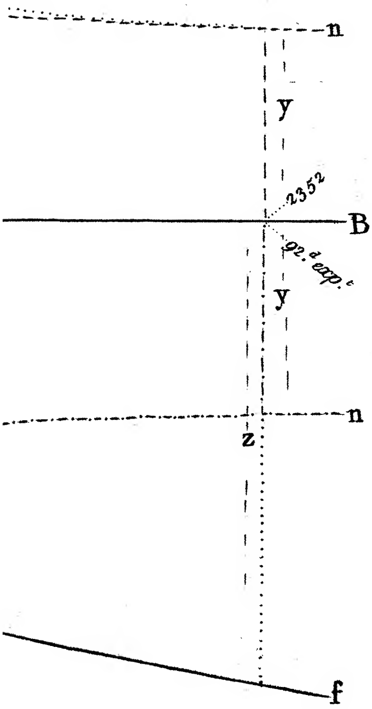

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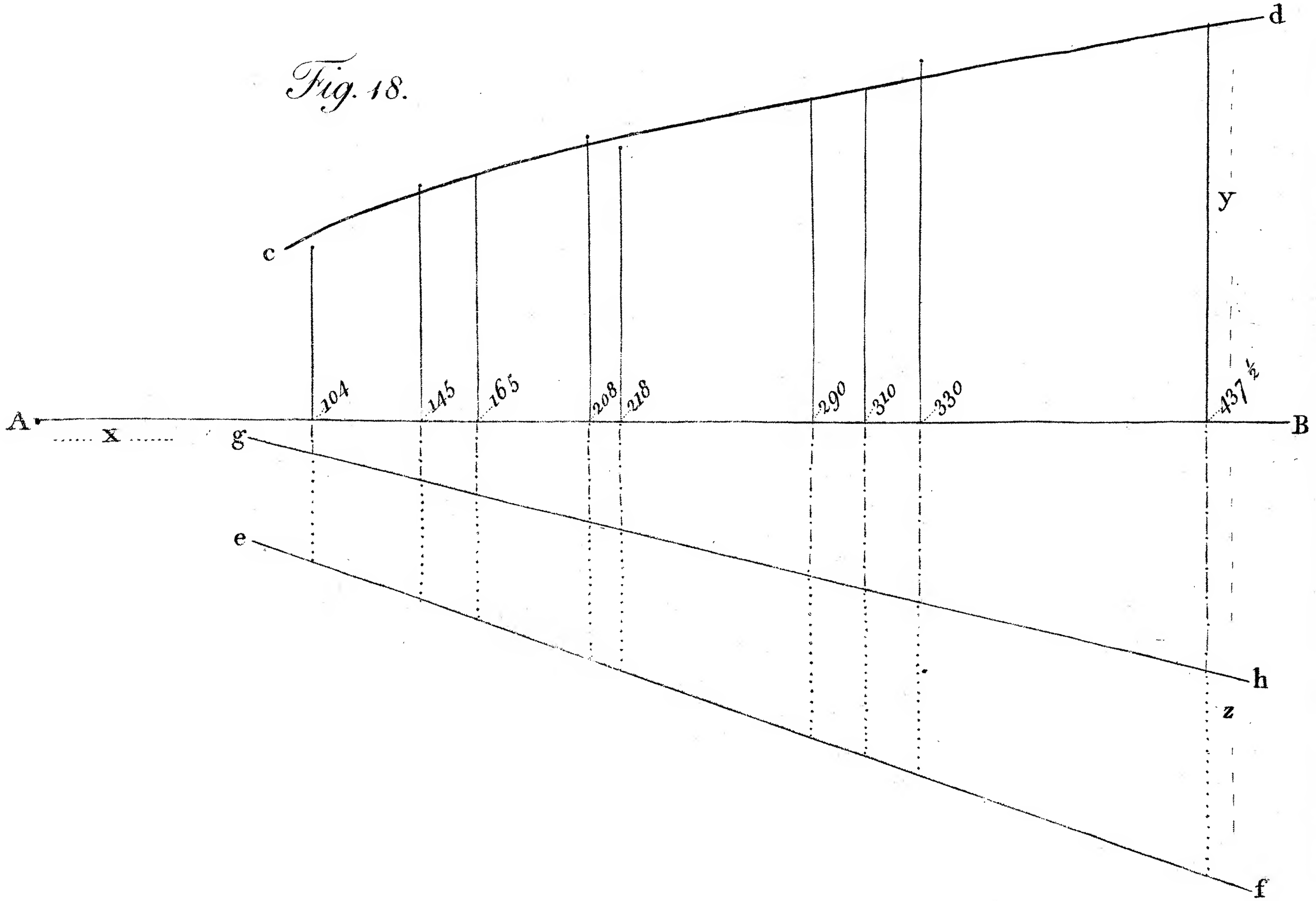

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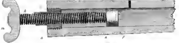

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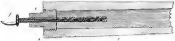

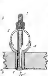

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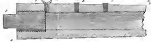

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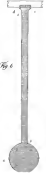

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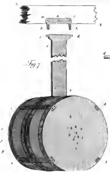

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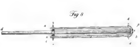

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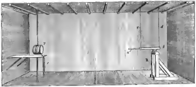

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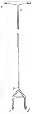

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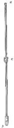

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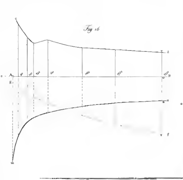
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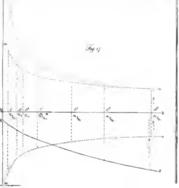
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